37

CHEMICAL PHOSPHORUS REMOVAL FROM MUNICIPAL WASTEWATER BY THE ADDITION OF WASTE ALUM SLUDGE TO THE ACTIVATED SLUDGE SYSTEM

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DECLARATION BY CANDIDATE

I, SEAN P. B. POWER, hereby declare that this thesis is my own work and that it has not been submitted for a degree at another University.

Signed by candidate

September 1992.

SYNOPSIS

In many cases, waterworks waste alum sludge is disposed of by discharging it into a stream. In this investigation the disposal of alum sludge to activated sludge systems treating municipal sewage is investigated. The advantage is that it is a better method of alum sludge disposal, and moreover the addition of alum sludge removes phosphorus from the wastewater through chemical precipitation.

Two long sludge age (20 days) Modified Ludzack Ettinger (MLE) predenitrification systems receiving unsettled municipal wastewater at a controlled concentration of 500mg COD/l as influent were operated for a period of 305 days, one as an Experimental system and the other as a Control system. The anoxic mass fraction was large (70%), to mimic many long sludge age nitrification/denitrification systems in operation in South Africa. Nitrate was added into the anoxic reactors to maintain anoxic conditions so that biological excess phosphorus removal would not take place and interfere with the chemical removal performance.

Alum sludge was dosed into the anoxic reactor of the experimental system on a once daily batch basis at a controlled rate varying between 173 mg inorganic suspended solids (ISS/d) to 491 mgISS/d which is equivalent to 17,3 to 49,1 mgISS/l influent flow. The alum sludges used in the investigation were produced at the Kloof Nek and Steenbras water treatment works which treat brown waters of the Western Cape. The total suspended solids (TSS) of these sludges averaged 61% organic (volatile), 39% inorganic (ash), 0,005 mgN/mgTSS and 0,61 mgCOD/ mgTSS. Accepting that the after incineration ash content is entirely Al_2O_3, a reasonable assumption for the soft waters of the Western Cape, and confirmed with unused alum, the Al content of the sludge is 0,53 mgAl/mgISS or 0,20 mgAl/mgTSS.

By monitoring the P removal in the experimental and control systems it was found that at steady state the alum sludge stimulated a P removal of 0,18 mgP/mgISS added, at a mixed liquor pH of 7,6. Based on a 0,53 mgAl/mgISS ratio the phosphorus removal was one third of the stoichiometric value.

A series of stirred jar batch tests were also conducted using alum sludge and commercial grade alum as precipitants at preselected pH values in the range 6,8 to 7,8. It was observed in these tests that:

(1) P removal is affected by the initial P mass to aluminium mass dosed ratio; the percentage stoichiometric P removal was reduced under excess aluminium conditions, ie at low initial mgP/mgAl doses;

(2) The amount of P removed decreases with increasing pH in the range considered;

(3) The percentage stoichiometric P removal achieved using alum sludge compared favourably with the P removal obtained using commercial grade alum at similiar dosing ratios and pH values in the batch tests;

(4) Due to the difference in hydraulic flow regimes between the batch tests and activated sludge reactor, the P removal observed in the activated sludge reactor corresponded to the removal achieved in a batch test at 10 days.

Other observations made from the experimental work are:

(5) the VSS of the alum sludge was not biodegradable and accumulated with the sludge in the biological reactor, and sludge production was increased by the mass of alum sludge added; the increased VSS and TSS concentrations need to be taken into account in the design of the secondary settling tank.

(6) 51% of the alum sludge COD was soluble unbiodegradable and escapes with the effluent; the remaining 49% was unbiodegradable particulate, hence no increase in oxygen demand was observed;

(7) the effluent TKN from the experimental system was negligibly higher than that from the control system, due to the small TKN mass dosed via the alum sludge, ie only approximately 2,7% of the total TKN passing through the system daily;

(8) the dewaterability of the the alum sludge was rather poor, yielding SRF and CST values of 70×10^{12} m/kg and 25 seconds respectively. However, the values for the activated sludge/alum mixture (45% of TSS being alum sludge TSS) was the same as that of the activated sludge only, ie 20×10^{12}m/kg, indicating that the dewaterability of the alum sludge is improved by its retention in the activated sludge plant. An improvement in dewaterability could not be obtained by simply mixing the two sludges. It appears therefore that the improvement arises from the exchange of the OH^- with PO_4^{3-} on the Al^{3+} thereby changing the gelatinous $Al(OH)_{3(s)}$ to an $AlPO_4$ precipitate;

(9) COD removal, nitrification and denitrification were not affected by alum addition;

(10) the alum/activated sludge mixture settled slightly better than the activated sludge alone.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 EUTROPHICATION OF WATER IMPOUNDMENTS

The rapid urbanization of catchments in South Africa led to a deterioration of the quality of water in impoundments due to eutrophication. The two principal plant nutrients responsible for this phenomenon have been identified as nitrogen and phosphorus. Of these phosphorus is a conservative limiting nutrient since nitrogen can be introduced into waters from the atmosphere through aquatic plant species notably the blue green algaes. It was for this reason that legislation was promulgated in August 1980, which limited the soluble orthophosphate concentration in treated municipal wastewaters discharged to certain sensitive catchments to 1 mg/ℓ (as PO_4-P) (Government Gazette, 1980). This legislation, which was enforced from August 1985, gave impetus to research into biological phosphorus removal in activated sludge plants. The biological P removal method was adopted in preference to chemical precipitation to minimize the mineralization of the surface waters that would have taken place with chemical addition. The biological P (and N) removal research proved very fruitful and has enabled efficient Biological Excess Phosphorus Removal (BEPR) plants to be designed, but in general it was found that the phosphorus removal capacity of these BEPR plants is largely dependant on the Readily Biodegradable Chemical Oxygen Demand (RBCOD) concentration present in the influent sewage.

The lack of control over the wastewater composition means that it is not always possible to meet the required effluent phosphorus standard due to low RBCOD concentrations in the influent sewage. Additional measures such as the production and elutriation of short chain volatile fatty acids produced through acid fermentation of primary sludge are often required to augment the influent RBCOD to improve BEPR. (Barnard, 1984; Lilley I et al., 1990).

An alternative to acid fermentation to augment BEPR, is chemical dosing to precipitate the remaining phosphorus. Chemical dosing either in the form of aluminium or iron salts, can take place at various points in the systems

such as directly into the biological reactor of the activated sludge system or into the effluent after secondary settling. Both dosage points have disadvantages in that they lead to increases in the total dissolved solids concentration and reduce the H_2CO_3* alkalinity (see footnote page 1.5) and pH of the treated water. In contrast, if instead of commercial aluminium sulphate (alum), waste alum sludge from waterworks were to be dosed into the activated sludge, the aluminium hydroxide in the alum sludge may be able to precipitate aluminium phosphate via the exchange of the hydroxides with phosphate. This would not only lead to chemical P removal without an H_2CO_3* alkalinity and pH reduction but also provide a useful disposal means of waste alum sludge from waterworks. This may be particularly useful in smaller towns where biological P removal is not incorporated into the activated sludge plant. Disposal of the alum sludge into the activated sludge plant would provide a convenient disposal means for the alum sludge, since sewage plants cater specifically for sludge treatment and disposal with the added benefit of achieving some P removal.

1.2 ALUM SLUDGES

Commercial aluminium sulphate is a commonly used coagulant in water treatment plants based on sweep coagulation, to remove turbidity from potable water supplies. In the Western Cape alone there are 5 plants treating brown coloured waters using aluminium sulphate as a primary coagulant to remove humic and fulvic acids, viz. Constantia Nek, Kloof Nek, Steenbras, Wemmershoek and Blackheath. The alum sludge produced in this operation consists principally of gelatinous inorganic aluminium hydroxide [$Al_2(OH)_{3(s)}$], and additionally the organic material removed from the water. Because the Western Cape waters are obtained from Table Mountain sandstone areas, the waters are very soft and contain little calcium or magnesium. As a result neglible inorganic material is removed by the alum sludge. The alum sludges produced at these water treatment plants have low solids concentration (0.2-0.8%) and generally exhibit poor dewatering characteristics due to the high proportion of gelatinous aluminium hydroxide in the sludge.

In the past not much attention was given to the disposal of these alum sludges, and they were largely returned to the watercourses from which the raw water source was drawn. Recently however waterworks authorities have begun to investigate alternative alum sludge disposal methods.

The poor dewatering characteristics of alum sludges as well as restrictions on available land, often leads to the need for removal of water from sludges using operations such as dissolved air flotation or centrifugation, to achieve the solids concentrations required for economical transport and disposal to landfills. Sludge dewatering and disposal operations require additional technical and maintenance staff at waterworks plants and consequently contribute considerably to the cost of water treatment. Clearly to be able to dispose of the alum sludge into an activated sludge system may be a convenient disposal means for the alum sludge with the added benefit of obtaining some additional P removal from the municipal effluent.

Disposal of alum sludge into activated sludge plants has received some attention recently and is practiced at full scale at Grabouw (Palmer, 1985). It has merit in that the sludge handling facilities for the waterworks and wastewater treatment plant can be combined obviating the need for additional technical and maintenance staff at the waterworks.

1.3 RESEARCH OBJECTIVE

From a sludge management point of view, the benefits of disposing of alum sludge into an activated sludge plant are clear and have been outlined above. However, the technical benefits of this disposal option have not been clearly defined. Some of the Grabouw results (Palmer, 1985) and a preliminary laboratory investigation (Haring, 1985), both reviewed in Chapter 2, demonstrated the method was worth pursuing so accordingly an investigation was initiated in 1989 to:

(1) Evaluate the ability of alum sludge to precipitate phosphorus in the activated sludge system.

(2) Determine the negative effects (if any) on the activated sludge biological treatment and the effluent quality.

(3) Examine the effect of alum sludge dosing on sludge production and dewaterability.

1.4 SCOPE OF WORK

In order to achieve the above objectives, two identical laboratory scale Modified Ludzack-Ettinger (MLE) systems were set up, namely, an Experimental system to which alum sludge was dosed daily, and a Control system not receiving dosed alum sludge. Apart from the alum dose to the Experimental system all other operating parameters were identical. The two systems were operated for a period of 305 days during which time their behaviour was monitored and compared. The observations made during this period enabled the phosphorus precipitation ability of alum sludge in activated sludge plants to be determined in terms of alum sludge dosed. The effect of alum sludge dosing on other parameters such as oxygen consumption rate, effluent quality, and sludge production and dewaterability, was also evaluated.

With regard to dewaterability, Specific Resistance to Filtration (SRF) tests were done on sludges drawn from both the Experimental and Control systems, enabling conclusions regarding effect of alum sludge dosing on the dewaterability of activated sludge to be made.

To evaluate the effect of the activated sludge on the precipitation performance, a series of stirred jar batch tests containing known masses of orthophosphate were done at various controlled pH values with both waste alum sludge and commercial aluminium sulphate as precipitants and the P removal/mg alum dosed achieved, was compared with that obtained in the Experimental system. The batch tests also allowed a comparison to be made between the P removal obtained with commercial aluminium sulphate and with waste alum sludge.

1.5 OVERVIEW OF THESIS

In Chapter 2, a literature review is presented which describes commonly used methods used for disposing of waterworks alum sludges, previous experiences of alum sludge dosing to activated sludge plants, and a review of work done on the precipitation of phosphorus using commercial aluminium sulphate.

In Chapter 3, the results and analysis of all the experimental work done during this present investigation, are presented.

Chapter 4 summarizes the major conclusions from the experimental work.

H_2CO_3* **ALKALINITY** is the alkalinity obtained when titrating with a strong acid down to the carbonic acid equivalent solution. Also called "total alkalinity" or "alkalinity".
In this thesis it will be referred to as H_2CO_3* alk. in units mg/*l* as $CaCO_3$.

CHAPTER 2

LITERATURE REVIEW

2.1 SURVEY OF WATERWORKS SLUDGE DISPOSAL METHODS

Historically little attention has been paid to the disposal of waterworks sludges. Sludges produced were often discharged directly back into the watercourses from which the water supply was drawn. In America this means of sludge disposal was accepted until the 1960s, when it was recognized that waterworks sludges were also "pollutants" and should not be returned to watercourses. A survey undertaken by Burd (1968) for the US Department of the Interior into methods used for the disposal of waterworks sludges in the USA gave the following breakdown of disposal methods:

Table 2.1: Methods used to dispose of waterworks sludges in the USA

Method of Disposal	% of Total Plants surveyed
Direct return to watercourse	58%
Direct disposal to drying beds or lagoons	30%
Storm or sanitary sewers	9%
Other methods	3%

South African water supply agencies also have begun to reappraise their methods of sludge disposal in recent years. Two instances of such reappraisal follow.

A review of the methods used by the Rand Water Board's water treatment plants, (Acton 1985), indicates that historically the Board has been fortunate to have had easy methods for the disposal of sludge. Methods employed have varied from lagooning and subsequent removal, to direct pumping of sludge into disused mines. Recommencement of mining activities in the area and pressures of land usage prompted the Board to investigate the dewatering of sludges using centrifuges, belt and plate presses.

At present some waterworks sludges in the Western Cape are discharged back into streams or directly to sea. This practice is however under review and a centrifuge has been installed at the Constantia Nek works.

2.2 SOURCES OF WATERWORKS SLUDGES

Waterworks sludges may be divided into basically two types, those produced in the coagulation process and those produced by plants having water softening facilities. Alum sludges produced by coagulation predominate, and are more difficult to thicken or dewater mechanically than other sludges and therefore pose a greater sludge disposal problem. In this investigation attention was focused on the effect of disposal of alum sludge into the activated sludge plant, and thus only the characteristics of this type of sludge are considered in the review.

Alum sludges produced by Coagulation

Coagulation is the process by which small particles are combined into large aggregates. It is an essential part of waterworks plants and is used in conjunction with sedimentation and filtration to remove particulates from water. Coagulation is also used extensively in removing brown colour due to fulvic and humic acids, so commonly found in waters of the Western and Southern Cape of South Africa.

The chemicals used in the coagulation process destabilize the colloidal particles. These destabilized particles are then brought into contact with each other by a gentle stirring action in flocculators. The aggregates formed in the coagulation-flocculation process are then removed from the water in settling-filtration tanks. The settling tank underflow and the backwash water from the filters together form the sludge flow from the waterworks.

The characteristics of waterworks sludges are a function of the raw water characteristics and the chemical used as a coagulant. Generally aluminium salts (III) of which $Al_2(SO_4)_3$ or alum is the most common form are in widespread use in coagulation processes both for the removal of colour and clays.

When alum is added to water it dissolves readily. The sulfate ions disperse in the water simply as SO_4^{2-}. The aluminium ions hydrolyze and, under the pH conditions generally found in water treatment works, form many aluminium hydroxide complexes such as the following:

$$Al^{+++} + 2H_2O \longrightarrow Al(OH)_2^{+} + 2H^{+} \qquad (1)$$

$$Al^{+++} + H_2O \longrightarrow Al(OH)^{++} + H^{+} \qquad (2)$$

$$7Al^{+++} + 17H_2O \longrightarrow Al_7(OH)_{17}^{4+} + 17H^{+} \qquad (3)$$

$$Al^{+++} + 3H_2O \longrightarrow Al(OH)_{3(s)} + 3H^{+} \qquad (4)$$

The aluminium hydroxide precipitate $Al(OH)_{3(s)}$ that is formed is amorphous and gelatinous. This material coats the colloids with a sticky gelatinous sheath which provides additional targets for the original solids and so form large agglomerates or flocs in the flocculation tank. This method of solids removal is called coagulation-flocculation and is usually employed with low turbidity waters containing colour. Sludges formed by this mechanism usually have poor dewatering characteristics due to the presence of the gelatinous aluminium hydroxide.

Coagulation also can occur by an adsorption mechanism, in which negatively charged colloids are absorbed onto the positively charged monomers and polymers rendering them unstable and forming aggregates when contacts occur. This type of coagulation is best suited to high turbidity waters containing stable particulate material. Less coagulant is needed and results in a more compact and less gelatinous sludge which dewaters more readily than those produced in sweep coagulation.

The alum sludge formed at the Western and Southern Cape water treatment plants is of the former type, i.e. from sweep coagulation, since these waters are characteristically very soft (low in calcium and magnesium), and are generally treated using alum to remove the brown colour due to humic and fulvic acids.

It will be noted from the above reactions (1) to (4) that alum is an acid in the respect that protons are liberated upon alum addition to water. The estimated loss of $H_2CO_3^*$ alkalinity (see footnote page 1.5) is about 0.55mg/l as $CaCO_3$ per mg/l alum dosed. This loss of alkalinity reduces the buffer capacity of the water (or pH of the water), and in the case of the soft waters of the Western and Southern Cape would need to be rectified by dosing lime or some other alkali. As examples, the dosing chemicals and rates at Kloof Nek and Steenbras waterworks, both treating the brown coloured waters of the Western Cape are given in Table 2.2.

The waters treated at these plants are extremely soft and have very low turbidities, characteristically NTU values in the range 1,7 to 3,7. Both plants incorporate sweep coagulation, settlement, filtration, liming and carbonation. The coagulation produces sludges with a high proportion of gelatinous alum hydroxide.

Table 2.2: Chemical dosing at the Steenbras and Kloof Nek waterworks (from Cape Town City Engineer's 1987/1988 Annual report See Appendix A)

Water Treatment Works:		Kloof Nek	Steenbras
Water treated	m^3/h	500	4375
Sedimentation period	h	5.4	2.8
Filtration rate	m/h	3.4	4.5
Chemical Dosage :			
Aluminium Sulphate	mg/l	58.2	27.4
Sodium Aluminate	mg/l	9.7	4.7
Lime	mg/l	41.2	30.2
Chlorine	mg/l	2.4	2.3
Coke	mg/l	8.4	9.2

The above information is relevant because the alum sludges used in the experimental investigation outlined in this thesis were obtained from these two plants.

2.3 TREATMENT OF WATERWORKS SLUDGES

It is not the intention in this literature survey to review all the aspects of waterworks sludge treatment and disposal, as this is not particularly relevant to the investigation of disposing of alum sludges in activated sludge systems. Only a brief outline is given below of the kind of treatment and disposal options currently in use for waterworks sludges, and then only for the alum sludges produced by sweep coagulation.

The treatment that alum sludges receive depends by and large on the disposal option adopted and the economics. It is for this reason, cynically speaking, that discharging the sludge back into the stream is the "best" option because it requires the least sludge treatment and is therefore the most economical disposal option. Any other disposal option will require sludge treatment and as a result be at a higher cost.

2.3.1. Treatment :-

In outline the treatment of alum sludges involves the following:

i) **Thickening** - to remove as much free water from the sludge as possible in order to reduce the sludge liquid volume.
This is normally done by gravity sedimentation with or without polyelectrolyte addition. Usually solids concentrations of around 3% are achieved by gravity sedimentation but with polyelectrolytes higher concentrations can be achieved. In contrast to gravity sedimentation, Bratby and Marais (1977), demonstrated that alum sludge also could be thickened by flotation and with low polyelectrolyte addition achieved concentrations of 12%.

ii) **Dewatering** - to remove the bound and capillary water from the solid matter.
The processes that are employed to achieve this are mechanical in nature. Sludges with solids concentrations greater than 20% are produced enabling sludge to be handled by mechanical methods thereby simplifying the handling operations for disposal such as transport.

A number of laboratory tests have been developed to determine the dewaterability of sludges, such as Capillary Suction Time (CST) and Specific Resistance to Filtration (SRF). These are briefly reviewed below to provide some background to these tests to enable evaluation of the influence of sludge addition on the dewaterability of the activated/alum sludge mixture. Mechanical equipment employed for sludge dewatering includes vacuum filtration, centrifuges, pressure filtration and filter belt presses.

iii) **Sludge Drying** - this is the final stage in sludge treatment before disposal. It is basically thermal or evaporative in nature and removes the remaining moisture which essentially forms a part of the solid material. There are two principal means for sludge drying, both of which are evaporative, namely lagooning and drying beds. Heat drying appears not to be practiced in South Africa probably due to its expense and the dry subtropical climate.

Lagooning - Sludges may be discharged directly to purpose made impoundments. Evaporation and percolation take place which dry the sludge. The size of these impoundments is dictated to by a number of factors such as the concentration of the feed sludge, whether the discharge to the lagoons is continuous or intermittent, whether or not a decant system is provided for supernatant, and the climate of the region. Often with lagoons, mechanical dewatering is not practiced with the result that for alum sludges, this method does not produce a final product suitable for disposal to landfills because concentrations in the lagoons vary from only 2% at the surface to about 10% at the bottom. Lagooning without mechanical dewatering is more suited to lime sludges which dewater readily, and final concentrations of 50% have been attained.

Drying Beds - These are similar to lagoons but have underdrains constructed under the floor. The sludges are spread over the underdrains and left to dry in the sun. This method is more suited to the disposal of alum sludges, and concentrations of 20% which are suitable for disposal to landfills can be obtained. Palmer (1985)

reported sludge concentrations of 10% after 3 days, 30% after 5 days and 45% after 7 days on pilot scale drying beds at Grabouw in January (summer) 1985 during sunny weather.

2.3.2. Note on Sludge Dewaterability Tests

The principal two tests with which the dewaterability of a sludge (water or wastewater) is assessed are the Capillary Suction Time (CST) and the Specific Resistance to Filtration (SRF).

In the CST test, the time (in secs.) for filtrate to be drawn out of the sludge for a specified distance by the capillary action of dry filter paper is measured. Generally sludges with CST values of 50 secs. or less are regarded as ones that can be dewatered by mechanical means. A standard shear test is sometimes done in conjunction with the CST to determine the strength of the flocs.

In the SRF test the resistance to filtration by one square metre of sludge comprising 1 kg dry mass sludge solids is obtained by measuring the rate of filtrate accumulation under a specified pressure differential of 49 kPa. In calculating the SRF from the filtration rate it is assumed that (i) the sludge is incompressible, (ii) the resistance of the filter surface is negligible in comparison to that of the sludge cake, and (iii) the mass of sludge deposited on the filter is proportional to the filtrate produced through the sludge concentration. The major advantage of the test is that the SRF result is a function of the sludge properties such as particle size distribution, the presence of hydrophilic colloidal matter (as in the case of alum sludge) and the structure of the sludge. The SRF values are theoretically independent of total suspended solids concentration. The compressibility of the sludge can be assessed also with the SRF test by varying the pressure differential. Details of the test procedure and results obtained from it on various sludges are given in "Manuals of British Practice in Water Control, Unit Processes - Sewage Sludge II, conditioning, dewatering and thermal drying".

According to Kavanagh (1980), there is a relationship between the CST and SRF for chemically conditioned municipal sludges, i.e.

$$\log(CSTs - CSTw) = ß\log(SRF * Xt)$$

where

CSTs,w = CST of the sludge and of water

and Xt = total suspended solids concentration (kg/m^3).

Municipal sludges presumably are wastewater or biological sludges. Whether this relationship also holds for principally inorganic waterworks sludges is uncertain.

Other simpler tests than CST and SRF are also sometimes employed but these are not as reliable as the CST and SRF, e.g. a "visual observation by beaker" test and a "gravity drainage" test. It should be noted that these tests, including also the CST and SRF, are not ideal simulations of full scale mechanical dewatering processes but enable semi-quantitative comparisons between different sludges to be made. For an overview of CST and SRF values on different wastewater sludges, see Smollen (1986). Generally speaking, sludge with CST and SRF values less than 50 secs. and 10.10^{12} m/kg are regarded as ones that can be successfully and economically dewatered by mechanical means.

With regard to water works alum sludges, Palmer (1985) reported SRF values for these sludges at various waterworks in the Western and Southern Cape (Grabouw, George, Mossel Bay, Hermanus and Stellenbosch) to be in the range 28.10^{12} to 46.10^{12} m/kg.

2.4 SLUDGE DISPOSAL ALTERNATIVES

Other than returning the sludge to the stream (which is no treatment at all), or thickening, dewatering and drying as discussed above and disposal by land filling, there are not many other alternatives for waterworks sludge treatment and disposal. Unlike sewage sludge it has extremely little organic and nutrient value; while this makes the sludge easier to treat and handle in that it does not require stabilization and pasteurization, it does, after treatment, leave a rather useless material to dispose of. But the sludge does contain large quantities of aluminium hydroxide which is a useful constituent. If this aluminium hydroxide in the sludge can be utilized beneficially in some way, then a possible beneficial sludge disposal alternative can be found.

In looking for such disposal alternatives, two possible beneficial uses of the aluminium hydroxide are apparent, i.e. alum recovery, and chemical phosphorus removal in activated sludge systems.

2.4.1 Alum Recovery

In alum recovery from alum sludge, the alum sludge is first thickened to a concentration of at least 2%. The thickened sludge is then dosed with sulphuric acid (H_2SO_4) to produce aluminium sulphate from the aluminium hydroxide which is entrapped in the sludge. Approximately 8% more acid is required for the reaction than the stoichiometric value, 1.9 $kgH_2SO_4/kgAl(OH)_{3(s)}$, since a pH of 2 is required. This low pH has a beneficial effect on the dewatering characteristics of the sludge. Impurities must then be removed from the reactant.

Recovery figures of 50 to 70% have been obtained using this method. Problems encountered with this process are that yields are low, the formation of gas bubbles which cause problems in gravity thickeners and a progressive deterioration in the quality of alum due to the accumulation of impurities such as colour, iron and manganese. Despite the improved dewatering characteristics of the sludge, the cost of the method and the higher degree of operator skills required are prohibitive factors which have led to the lack of popularity of this approach.

2.4.2 Chemical P Removal in Activated Sludge Plants

In order to minimize eutrophication of surface waters from point sources of phosphorus, treated municipal wastewaters are required by law to contain less than 1 mgP/l dissolved orthophosphate. Because only about 15 to 20% of the phosphorus in municipal wastewaters is removed in normal biological processes of wastewater treatment such as activated sludge, other methods of removal of the remaining P need to be found. Because in removing the P from the wastewater it is required to be transferred from the liquid to the solid or sludge phase, two routes are open for additional P removal i.e. biological excess P removal (BEPR) or chemical precipitation. In order to limit surface water mineralization i.e. the build up of chlorides and sulphates through a high degree of indirect municipal reuse of the waters, especially in the Transvaal, the biological route for P removal is the preferred method. However there are instances where the P removal obtained biologically is insufficient and then further removal needs to be obtained by chemical precipitation.

For chemical P removal, iron or aluminium chlorides or sulphates are dosed to three possible points in the plant viz; (1) to the influent before primary sedimentation (pre-precipitation), (2) into the biological reactor (simultaneous precipitation), or (3) into the effluent after secondary sedimentation (post-precipitation).

Since the objective of the experiment investigation of this thesis is to examine chemical P removal by alum sludge disposal into the biological reactor, only simultaneous precipitation with aluminium salts will be briefly reviewed.

2.5 CHEMICAL P REMOVAL

2.5.1 Phosphate Removal Using Aluminium (III) Salts

Ortho phosphate, polyphosphate (condensed phosphate) and organic phosphate are the three principal compounds constituting the total P found in municipal wastewaters, with about 80 to 85% of the total P being dissolved ortho phosphate. In measuring the total P concentration in wastewaters, the samples

are acid digested which converts most non-ortho phosphate forms to ortho phosphate ("Standard Methods for the Examination of Water and Waste Waters", 1985) and then the total orthophosphate concentration is determined spectrophotometrically. The conversion of non ortho-P to ortho-P also takes place in sewage treatment plants through biological action. This conversion is a necessary first step to the chemical removal of non ortho-P.

Aluminium salts, in particular alum, are commonly used to remove phosphate from waste waters. The removal mechanism has been the subject of much controversy. Data supporting the concept that phosphates were removed by adsorption onto precipitating aluminium hydroxide flocs was presented by Lea et al. (1954) and Hendriksen (1962). Contradictory evidence has however been presented by Stumm (1964), and Cole and Jackson (1950) supporting the theory of phosphate removal by the precipitation of insoluble metal phosphates. Considerable disagreement on the stoichiometric relationship in the cation-phosphate reaction also exists. Stumm proposed that the following generalized relationship is reasonable between the trivalent cations and phosphates at low cation to phosphate ratios:

$$M^{+++} + H_2PO_4 \longrightarrow MPO_4 + 2H^+$$

provided that sufficient time elapses for the reaction to be completed. Stumm further suggested that tripolyphosphates are not removed to any significant extent due to the formation of soluble complexes such as:

$$MP_3O_{10}^{--}$$

Stumm's stoichiometric relationship is however not borne out by removals achieved in practice. Stoichiometric values greater than 1 to 1 suggest that one or more of the hydrolysis products of Al^{+++} e.g. $[Al(OH)_2^+$, $Al(OH)^{2+}$, etc.] are involved in the precipitation of phosphate and not only Al^{+++} species.

A combination of precipitation, ion exchange and adsorption mechanisms most likely describes the reaction. It has been determined experimentally that the reactions are pH dependant, the optimum being in the range 5,5 to 6,5.

2.5.2 Disposal of Alum Sludge into Activated Sludge Plants.

The disposal of alum sludge which contains a large proportion of aluminium hydroxide to the activated sludge reactor is a possible means for achieving chemical P removal. From a chemical precipitation point of view, this method is perceived to be advantageous over straight alum addition because not sulphates but hydroxides will be exchanged with phosphates; also this will add rather than take away from the water's alkalinity, i.e. the negative effects of aluminium sulphate addition on the alkalinity of the water have already taken place at the waterworks, and will not take place again at the wastewater treatment plant when the waterworks alum sludge is added.

This method of alum sludge disposal was implemented at the Grabouw activated sludge plant by Palmer (1985) in November 1984 and no adverse effects were noted by the end of February 1985. The effect of alum sludge dosing on the phosphorus removal could unfortunately not be quantified as effluent phosphorus concentrations from the activated sludge plant were not measured: The alum sludge was dosed as a means of using the sludge handling and drying facilities at the activated sludge plant which was nearby the waterworks.

Following on from the Grabouw experience reported by Palmer (1985), Haring (1985) operated two laboratory scale completely mixed aerobic activated systems one experimental to which alum sludge was dosed, the other a control against which the effect of the alum sludge dosing could be compared. All design and operating parameters such as sludge age (20 days) etc. were identical. From measurements of effluent COD, TKN and total P, no adverse effects from the alum dosing were noted in the experimental system. Comparing the P removal, it was calculated that the experimental system on average removed 37,2 mgP/d (2,4mgP/l) more than the control resulting from a daily alum dose of 264 mgISS (inorganic suspended solids, i.e. TSS-VSS). This gave a P removal to ISS ratio of 0,14 mgP/mgISS at a pH of 7,6.

2.6 OBJECTIVES OF EXPERIMENTAL INVESTIGATION

From the above two case studies, it appears that there is merit in the alum sludge disposal option by discharging into an activated sludge system. Consequently the objective of the investigation reported in this thesis is to comprehensively examine the effect of brown water alum sludge disposal into an activated sludge plant. This was done with the aid of an Experimental system to which the alum sludge is dosed and a Control system against which the experimental system is compared, to determine parameters such as:

(1) P removed per alum dosed;

(2) Effluent COD and TKN concentrations -
to check if COD and TKN from the humic and fulvic acids are released into the effluent and to check the effect of the alum sludge on nitrification;

(3) Effluent nitrate concentration and oxygen utilization rate -
to check the effect of alum sludge on denitrification and COD degradation and to check whether or not some materials in the alum sludge are biodegradable and so increase the organic load in the activated sludge plant;

(4) VSS and TSS concentration -
to check whether or not all the alum sludge VSS and TSS dosed contributes to sludge production and provide a cross check on its degradability or solubility;

(5) DSVI and filamentous organisms -
to check the effect of alum sludge activated sludge settleability and bulking;

(6) H_2CO_3* alk -
to check if increases in H_2CO_3* alk can be detected from the exchange between hydroxides and phosphates;

(7) SRF and CST -
to check the dewaterability of the alum/activated sludge mixture.

The experimental investigation set up to address the above issues is described in detail in the next chapter.

CHAPTER 3

EXPERIMENTAL INVESTIGATION

THE EFFECTS OF DISPOSAL OF ALUM SLUDGES INTO ACTIVATED SLUDGE PLANTS

3.1 INTRODUCTION

In order to examine the effect of disposing of alum sludges generated by water treatment works into activated sludge plants, two laboratory scale activated sludge systems were set up, one Control and one Experimental. The systems were identical in all respects, except that alum sludge was dosed into one of the systems, that is, the Experimental system. The two systems were operated for a period of 305 days during which time the phosphorus loading and the alum sludge dosage was varied while the COD load remained approximately constant.

3.2 DESCRIPTION OF OPERATION OF LABORATORY SCALE SYSTEMS

The configuration chosen for the two units was the Modified Ludzack-Ettinger (MLE) system as shown in Fig 3.1. In both the Experimental and Control MLE systems the combined volume of the reactors in each system was 10 litres. The anoxic reactor occupied 70% of this volume i.e. 7 litres. The large anoxic mass fractions were selected because with intermittent aeration systems these have been found to promote filamentous bulking by low F/M filaments, a major problem in South African activated sludge plants, (Gabb et al, 1989; Blackbeard et al, 1986, 1988; Warburton et al, 1991), so that the effect of alum sludge addition on sludge settleability and bulking could also be observed.

The aerobic reactor comprised 30% of the total reactor volume i.e. 3 litres. The reactor was aerated with compressed air to an average dissolved oxygen concentration of 2 - 3 mgO/l. Mixed liquor from the aerobic reactor passed over a U-tube weir into a clarifier where the settled sludge was recycled to the anoxic reactor at a ratio (s) to the influent of 1 to 1. (Marais and Ekama, 1976). The clear supernatant from the settler was collected cumulatively over 24 hours in an effluent bucket. Grab samples were then taken from this bucket for analysis of effluent quality.

CONFIGURATION OF LABORATORY SYSTEMS.

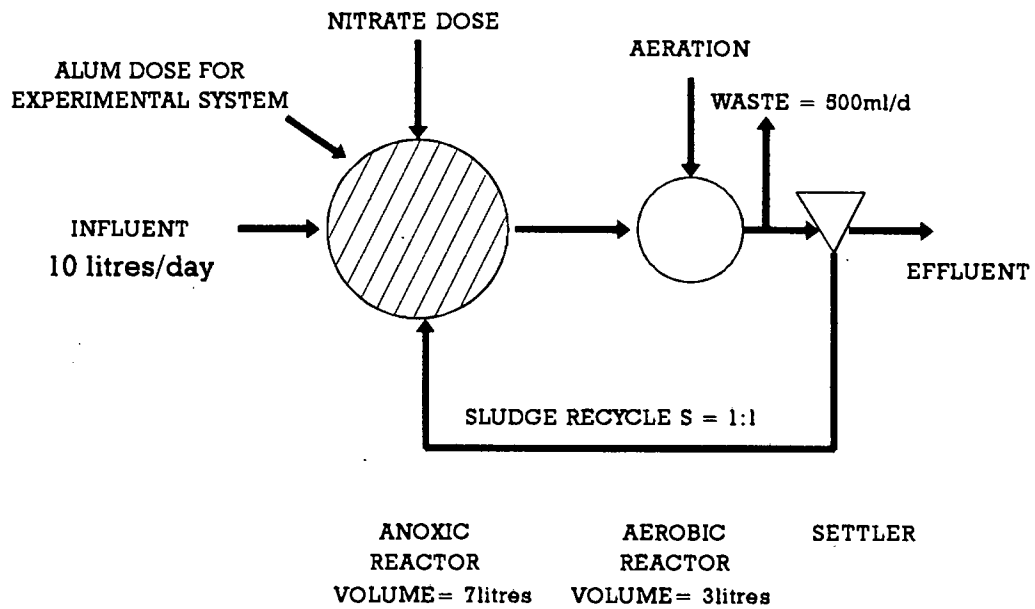


Figure 3.1

For the first 226 days, no mixed liquor recycle was included from the aerobic to anoxic reactor on either system. With no mixed liquor recycle, generally the nitrate concentration introduced to the anoxic reactor via the settler recycle was insufficient to ensure that anoxic conditions were maintained. To maintain anoxic conditions, i.e. a nitrate concentration >5mgNO_3-N/l in the anoxic reactor, a nitrate solution containing 500mgNO_3-N/l was dosed to the anoxic reactor of both systems at a nominal rate of 1 litre/day by means of a metering pump. This external source of nitrate ensured that the mixed liquor leaving the anoxic reactor always contained nitrate. This precaution was taken to ensure that the conditions in the anoxic reactor never became anaerobic (an absence of nitrate and dissolved oxygen), which may have led to biological excess phosphorus removal (BEPR); if BEPR were to take place in the systems, its extent would be uncertain and confound the P removal achieved by the alum sludge. The presence of nitrate in the mixed liquor leaving the anoxic reactor also ensured that the anoxic reactor was always loaded with more nitrate than its denitrification potential (Dp1) so that the possible inhibiting effect of alum sludge addition on denitrification could be determined. To ensure that the anoxic reactors did not entrain oxygen into the the mixed liquor from the air, a polystyrene cover was floated on the reactor surface to seal off the mixed liquor from the atmosphere.

To ensure sufficient phosphorus (P) in the influent sewage the P concentration was supplemented by adding a small volume of concentrated orthophosphate solution which increased the P concentration from around 10mgP/l to 25mgP/l

Both systems were operated at a 20 day sludge age which was controlled hydraulically by wasting 500ml daily (1/20th of system volume) from the aerobic reactor, prior to the addition of the alum sludge slug. Mixed liquor required for sampling and analysis was included in the 500ml/d sludge wastage. A long sludge age of 20 days is typical of full scale plants into which alum disposal is likely to take place. The waste sludge produced by long sludge age activated sludge plants, are generally disposed of directly to drying beds as they are "stable" (have a low specific oxygen demand, gO/gVSS.h and do not produce malodours upon drying). This obviates the need to anaerobically or aerobically stabilize the sludge. The effect of alum sludge on waste sludge anaerobic digestors was not studied in this investigation.

For the first 30 days of the investigation, the systems were fed raw sewage at the rate of 15 l/d. This sewage was collected from the Mitchell's Plain sewage works which is a 30Ml/d nitrification-denitrification plant treating only domestic sewage.

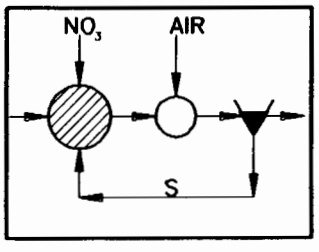
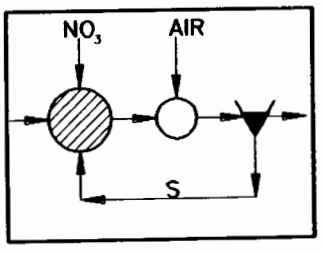
The sewage collected from this source was stored at 4^0C and fed to the two systems, after appropiate dilution with tap water to 500mgCOD/l, for a period of 2 to 3 weeks, after which a new batch of sewage was collected. Because the sewage was poorly buffered (H_2CO_3*alk approximately 150mg/l as $CaCO_3$), a teaspoon full of $NaHCO_3$ was added to the final 30 l volume of sewage fed to the two systems daily to buffer the influent and maintain the pH in the system above 7.0. From day 30 of the investigation the feed volume was reduced to 10 l/d because the high MLSS in the experimental system (which was to receive alum sludge) caused the settling tank to become overloaded with a consequent uncontrolled loss of solids from the system. The lower influent flow and COD load reduced the settling tank overflow rate and activated sludge MLSS. This enabled the settling tank to contain the sludge even when the sludge bulked at high DSVI's (350ml/g). At the time the influent flow was reduced, a batch of mixed liquor also was wasted to yield the required activated sludge MLSS concentration at the reduced COD load. Because by day 30, the pH of the mixed liquor was well above 7.0 the practice of adding $NaHCO_3$ to the influent was terminated on day 30 also. A summary of the initial operating conditions of the two systems is given in Table 3.1.

During the investigation, a number of changes were made to the two laboratory systems. The objective of these changes were to investigate the effect of:

(1) different waterworks alum sludges on P removal;
(2) different alum sludge doses on P removal;
(3) the mixed liquor a-recycle on the low F/M filaments and sludge settleability;
(4) cyclic loading of phosphorus with constant alum dosing on P removal.

Details of all the changes made to the laboratory systems during the investigation are listed in Table 3.2.

Table 3.1: Initial design and operating parameters of laboratory scale systems, the one being a control system against which the performance of the experimental system, to which alum sludge was added, could be evaluated.

System	Control	Experimental
Operating conditions	MLE without an a recycle and nitrate dosing into anoxic reactor. (a)	MLE without an a recycle and nitrate dosing into anoxic reactor. (a)
Schematic diagram		
Aerated volume	30%	30%
DO concentration	2-3	2-3
Feed	continuous	continuous
Sewage feed source	Mitchell's Plain raw	
Influent flow (l/d)		
day 1 to 30	15	15
day 30 onwards	10	10
COD conc. (mgCOD/l)	500	500
TKN conc. (mgN/l)	(40-60)	(40-60)
P conc. (mgP/l)	(10-30)	(10-30)
Nitrate dose (l/d)	1	1
Nitrate conc. (mgN/l)	500	500
Alum dose (ml/d)	-	50-650 (a,b)
Sludge age (d)	20	20
Temperature (°C)	20	20
Vol. of reactors (l)		
anoxic	7	7
aerobic	3	3
Nominal hydraulic retention time	24hrs.	24hrs.
Mixed liquor pH	7.3-8.0	7.3-8.0
Settler s-recycle	1	1

(a) See Table 3.2 for the day on which changes in these parameters were made.
(b) See Table 3.4 for the actual masses of COD, TKN, TSS, VSS and ISS dosed into the experimental system daily during the investigation.

Table 3.2 : **Operational changes made to the laboratory systems**

Day No	Change	Reason
1	Set up laboratory systems as shown in Fig. 3.1. Feed;15 litres of raw sewage at 500mgCOD/l from Mitchell's Plain works to each system per day. Dosed NaHCO3 to the influent.	
18	Started Nitrate dosage to Anoxic reactors on both systems.	To prevent Anoxic reactors becoming Anaerobic.
30	Reduced influent flow from 15l/d to 10l/d. Reduced sludge MLSS mass proportionately. Stopped NaHCO3 dosage to influent.	To alleviate overloaded settlers.
45	Began adding Kloof Nek alum sludge to the Experimental system at the rate of 173mg of Inorganic Suspended Solids (ISS)* per day.	
93	Changed source of alum sludge from Kloof Nek works to sludge from Steenbras works. Mass of sludge added daily increased to 212mgISS.	
181	Changed mass of sludge added per day to 424mgISS.	
226	Incorporated an a-recycle of 3.7:1 between the aerobic and anoxic reactors on Control system.	To investigate the effects of an a-recycle on the growth of filamentous organisms.
232	Changed source of alum sludge to Kloof Nek. Adding 227mgISS/d.	
236	Cyclic phosphorus load imposed on both systems.	

* The alum sludge contains COD, TKN, MLSS and MLVSS and each of these parameters were determined on the sludge. Since it is only the inorganic component that is effective for P precipitation, the alum sludge dosages were calculated in terms of the Inorganic Suspended Solids (ISS) which was found from the difference between the MLSS and MLVSS tests.

Table 3.2 Continued: **Operational changes made to the laboratory systems**

Day No	Change	Reason
263	Phosphorus load to both systems reduced.	To investigate the propensity of alum sludge to remove phosphorus at low influent concentrations
265	The a-recycle was removed from Control system.	The DSVI had risen to above 200ml/g from 100ml/g before the recycle was incorporated in the system.
270	Incorporated an a-recycle of 4:1 on the Experimental system from the aerobic to anoxic reactor.	To see if the recycle would cause similiar observations made in the Control system to occur.
286	Changed mass of alum sludge added to 491mgISS/d.	
311	Second settler installed on the Experimental system.	The settler was overloaded and sludge loss was occuring
312	No nitrate dose to control system.	The nitrate pump failed.
325	Experimental system closed down.	Sludge loss occuring.
357	Control system closed down.	

3.3 ALUM DOSING

The alum was dosed into the Experimental system in the form of a daily slug addition. This was necessary because the alum sludges were concentrated (3000-9000mgTSS/l) which made accurate dosing by continuous pumping very difficult. The concentrated alum sludges made daily slug addition convenient because only a small volume (50-650ml/d) needed to be added.

The alum sludges dosed to the activated sludge system in this investigation were obtained from two different water treatment works in the Western Cape, i.e. the Steenbras and the Kloof Nek waterworks. The alum sludges produced by these waterworks are the products of the treatment of "brown waters" which are coloured due to the presence of humic and fulvic acids. The measured parameters of the 4 batches of alum sludges obtained from these waterworks during the investigation for dosing to the Experimental system are given in Table 3.3. An extract from the Cape Town City Engineers Report showing some water treatment data for the Kloof Nek and Steenbras waterworks is given in Appendix A.

Table 3.3 : **Measured parameters of alum sludge batches dosed to Experimental system.**

Date 1989	Source of Alum	TSS mg/l	VSS mg/l	ISS mg/l	TKN mg/l	COD mg/l	% Ash mgISS/ mgTSS	N/VSS mgN/ mgVSS	COD/VSS mgCOD/ mgVSS
09/03	Kloof	4640	2910	1730	11.2	3530	37.3	0.0038	1.213
26/04	Steen	9054	4814	4240	47.3	4389	46.8	0.0098	0.912
12/09	Kloof	2920	2162	758	25.2	1943	26.0	0.0116	0.900
15/10	Steen	2454	1698	756	14.8	1795	30.8	0.0087	1.057
	Average	4767	2896	1871	24,6	2914	39,2	0.0084	1.020

From Table 3.3 it can be seen that the variation in parameters between batches of the Kloof Nek sludge are larger than between the Kloof Nek and Steenbras sludges, and so for the purpose of this investigation, the two sludges will be regarded as similiar.

In the process of coagulation with aluminium sulphate the following reaction is presumed to occur with the natural alkalinity:

$$Al_2(SO_4)_3+14H_2O+4Ca(HCO_3)_2+Mg(HCO_3)_2 \longrightarrow$$
$$2Al(OH)_{3(s)}+3CaSO_4+CaCO_3+MgCO_3+16(H_2O)+8CO_2$$

The waters in the Western Cape are "soft" (low in total disolved solids and alkalinity) with the result that the mass of inorganic precipitates like $CaCO_3$, $MgCO_3$ and $CaSO_4$ that form from natural alkalinity as shown above during coagulation/precipitation are neglible. Accepting that for the Cape soft waters the inorganic component of the alum sludge is principally the solid amorphous gelatinous precipitate $Al(OH)_{3(s)}$, the aluminium content of the alum sludge can be determined from the Inorganic Suspended Solids (ISS) concentration, where the ISS is the difference between the TSS and VSS. In determining the ISS of waste alum sludge the following reaction takes place during the combustion phase:

$$2Al(OH)_{3(s)} \xrightarrow{Heat} Al_2O_3 + \text{A little ash}$$

Accepting the ash fraction is small due to the virtual absence of solids like $CaSO_4$, $CaCO_3$, $MgCO_3$, silicates and clay, the mass of ISS is almost purely aluminium oxide Al_2O_3 which has an aluminium content of 53% of the measured ISS concentration for the alum sludges. In the evaluation of the P removal efficacy of the alum sludge, the data are calculated in terms of the ISS or Al content of the alum sludge. The mass of ISS dosed per day during this investigation as well as the masses of the other measured alum sludge parameters are given in Table 3.4.

Table 3.4: Masses of COD, TKN, TSS, VSS, and ISS dosed to experimental system via alum sludge.

Steady state period number	Period Day No.	Vol. ml/d	Source of Alum	ISS mgISS /d	COD mgCOD /d	TKN mgN/d	TSS mgTSS /d	VSS mgVSS /d
1-2	45 -93	100	Kloof	173	353	1.2	464	291
3-7	94 -181	50	Steen	212	219	2.4	453	241
8-10	182-232	100	Steen	424	439	4.7	905	481
11-12	232-265	300	Kloof	227	583	7.6	876	649
13	266-286	300	Kloof	226	539	4.4	736	509
14-15	287-325	650	Kloof	491	1167	9.6	1654	1104

3.4 SYSTEM EVALUATION

In order to evaluate the performance of the Experimental and Control systems during the investigation, the following parameters were measured virtually daily:

(1) Influent and effluent (unfiltered) COD concentrations;
(2) Influent and effluent (unfiltered) TKN concentrations;
(3) Influent and effluent (unfiltered) Total P concentrations;
(4) Anoxic and aerobic reactor and effluent nitrate concentration, which is the sum of the nitrate plus nitrite concentrations. The nitrite concentrations were measured occasionally and found to be generally less than about 3mgN/l;
(5) Filtered effluent turbidity;
(6) Aerobic reactor MLSS and MLVSS concentrations;
(7) Oxygen utilization rate (OUR) in the aerobic reactor;
(8) Sludge settleability in terms of diluted sludge volume index (DSVI);
(9) Filament identifications every 3 to 4 weeks;
(10) COD and TKN of the MLVSS to determine the COD/VSS and TKN/VSS ratio of the sludge every 3 to 4 days.

Apart from the above routine tests on the Experimental and Control systems, a number of ancillary tests and experiments were also conducted during parts of the investigation viz.

(1) Sludge dewatering tests on the alum sludge, activated sludge and alum/activated sludge mixture by using a Buchner funnel to determine the Specific Resistance to Filtration (SRF). (Izzett, 1989).

(2) Stirred jar batch tests over 20 days at different pH values and initial P concentrations to alum sludge dosage ratios to check the P precipitation ability of the alum sludge on its own. During these tests the pH was kept constant by adding measured amounts of strong acid from which it was possible to calculate the alkalinity gain during aluminium phosphate precipitation. (Airey, 1989).

The results of the routine monitoring on the two laboratory systems and that of the ancillary tests are listed in Appendices C, D and E, and discussed in detail below.

3.5 LABORATORY SYSTEM PERFORMANCE

3.5.1 N and COD balances

To gauge the reliability of the experimental data, N and COD balances were conducted on the measured data. To do this the routine data measured on the Control and Experimental systems were divided into steady state periods. The 305 days during which the Control and Experimental systems were operated similtaneously was divided into 15 steady state periods, the boundaries of these periods being defined by either the time at which a new sewage batch test was commenced or when an operational change was made to one of the systems. With the aid of a spreadsheet programme (QUATTRO), into which all the routine results were fed, the averages of the various measured system parameters for each steady state period were calculated. From these averages, the N and COD mass balances were calculated (also with the spreadsheet programme) for each steady state period. Print outs of the N and COD balance calculations are given in Appendix B and the procedure is set out below.

The N balance is checked by reconciling the mass of TKN plus nitrate entering the system with the mass of N leaving the system where the latter is given by the sum of the mass of TKN and nitrate in the effluent, the mass of nitrogen in the sludge wasted and the mass of nitrate denitrified. Mathematically the nitrogen balance can be expressed as:

Nitrogen balance

$$= (MNte + MNne + MNs + MNd)/(MNti + MNni) \times 100\ \%$$

where

MNti	=	mass of TKN in influent	(mgN/d)
MNni	=	mass of nitrate fed daily	(mgN/d)
MNte	=	mass of TKN in effluent	(mgN/d)
MNne	=	mass of nitrate in effluent	(mgN/d)
MNs	=	mass N required for sludge growth	(mgN/d)
	=	mass of N in sludge wasted per day	
	=	fn x mass of VSS wasted per day	

and -

fn = TKN/VSS ratio of the sludge which was measured for the Control and Experimental systems. An average fn value of 0,1 and 0.085 mgN/mgVSS was obtained for the Control and Experimental systems respectively.

The mass of nitrate denitrified daily (MNd) can be calculated from a nitrate balance on the anoxic reactor by subtracting the mass of nitrate leaving the reactor from that entering the reactor. This is expressed mathematically as follows:

$$MNd = MNni + MNnr - MNna \quad (mgN/d)$$

where

MNni = nitrate mass dosed daily into anoxic reactor (mgN/d)
MNnr = nitrate mass recycled to anoxic reactor via s and a-recycles (mgN/d)
MNna = nitrate leaving the anoxic reactor (mgN/d)

The MNnr and MNna nitrate masses were obtained from the nitrate concentration measurements in the anoxic and aerobic reactors and the effluent and MNi nitrate mass was determined from the volume of the 500mgNO_3-N/l solution dosed daily. Knowing the mass of nitrate denitrified, it is possible to calculate the mass of oxygen recovered in denitrification (MOd) and the oxygen demand for nitrification (MOn). The former is found by multiplying the nitrate mass denitrified by the stoichiometric value 2.86mgO/mgNO_3-N and the latter by multiplying the mass of nitrate generated (MNnc) by the stoichiometric value of 4.57mgO required/mg nitrate generated. The mass of nitrate generated (MNnc) is found from the sum of the masses of nitrate denitrified (MNd) and that leaving the system via the effluent (MNne), minus the mass of nitrate dosed into the system (MNni), or alternatively from the influent TKN mass (MNti) minus the sum of the effluent TKN mass (MNte) and the nitrogen wasted in the wasted sludge mass (MNsw) viz

$$MOd = 2.86 \times MNd \quad (mgO/d)$$
$$MOn = 4.57 \times MNc \quad (mgO/d)$$
$$MNnc = MNd + MNne - MNni \quad (mgN/d)$$
$$\text{or} \quad = MNti - MNte - MNsw \quad (mgN/d)$$

The two ways of calculating MNnc will give identical results if the N balance is 100%, but a difference will result if the balance is not 100%, the magnitude of the difference being related to the accuracy of the N balance. The calculated MOd and MOn values are required in the COD balance.

The COD balance involves reconciling the influent COD mass, (MSti), with the outflow COD mass where the latter is the sum of the masses of effluent COD, (MSte), COD in the wasted sludge, (MSws), and the mass of oxygen consumed in COD utilization under anoxic and aerobic conditions (MOc). The influent COD, effluent COD and the VSS of the wasted sludge were measured daily. The COD of the wasted sludge (MSws) was calculated from the mass of VSS wasted daily and average COD/VSS ratios measured in the Control and Experimental systems of 1.48 and 1.33 mgCOD/mgVSS respectively.

Mathematically, the COD balance may be expressed as follows:

$$\text{COD balance} = (MSte + MSws + MOc) \times 100 \times (1/MSti) \quad \%$$

The carbonaceous oxygen demand, M(Oc), was calculated as follows:

$$MOc = MOtm + MOd - MOn \qquad (mgO/d)$$

where

MOc = mass of oxygen required for COD utilization (mgO/d)

MOtm = measured mass of oxygen consumed daily in the aerobic reactor

= $(OUR \times 24 \times V_{aer})$ (mgO/d)

where

OUR = measured oxygen utilization rate (mgO/l/hr)

V_{aer} = volume of the aerobic reactor (l)

MOd = mass of oxygen recovered through denitrification obtained from the N balance (mgO/d)

MOn = mass of oxygen required for nitrification (mgO/d)

The OUR was measured by discontinuing the air supply to the aerobic reactor and then monitoring the dissolved oxygen (DO) concentration-time profile. The slope of the DO-time profile (obtained on a strip chart recorder) as the DO decreased from a value of around 4mgO/l to 1mgO/l was accepted as the biological OUR in mgO/l/h. The air supply was recontinued after the measurement. Over a period of 2 hours 3 to 4 OUR determinations were done daily and their average was accepted as the OUR over the whole 24 hour period. Occasional checks using a continuous on line automatic OUR recorder (Randall et al., 1991) indicated that in general no major fluctuations in the OUR occurred over a 24 hour period. The measured OUR comprises both oxygen utilization for COD (MOc) degradation and

nitrification (MOn). Knowing the mass of oxygen consumed daily (MOtm) from the measured OUR, the carbonaceous oxygen demand MOc was calculated by adding to this the MOd and subtracting MOn obtained from the N balance. The other parameters required for the the COD balance ie the mass of COD in the effluent (MSte) and the mass of of COD in the wasted sludge (MSws) were as follows; MSte from the measured effluent COD concentrations (Ste) and flow (Q) and MSws from the measured mass of VSS wasted daily times the measured COD/VSS ratio of the sludge viz

$$MSte = Q \times Ste \qquad (mgCOD/d)$$

$$MSws = f_{CV} \times \text{mass of VSS wasted daily} \qquad (mgCOD/d)$$

The COD/VSS ratio of the sludges in the Experimental and Control systems were measured regularly and an average value of 1.33 and 1.48 mgCOD/mgVSS respectively was obtained.

In the case of the Experimental system the additional TKN and COD load introduced into the system via alum sludge dosing was included in the calculation of the N and COD balances. It is for this reason that the COD, TKN, VSS and TSS of the alum sludge were measured, as well as the COD/VSS (fcv) and TKN/VSS (fn) ratios of the activated sludge in the Experimental system which included alum sludge. Because the COD/VSS and TKN/VSS ratio of the alum sludge is different to activated sludge, the COD/VSS and TKN/VSS ratios of the alum /activated sludge mixture in the Experimental system were different to the values of the activated sludge only in the Control system.
Details of the N and COD balances of each steady state period for the Experimental and Control systems are given in Appendix B. The N and COD balances achieved in the two systems for each steady state period during the investigation are given in Table 3.5.

Table 3.5 : **Mass balances on experimental data**

Steady state period No	Period Day No	COD Balance.		Nitrogen balance.	
		Ctrl	Exp	Ctrl	Exp
1	59 to 73	78%	78%	98%	98%
2	74 to 86	83%	87%	98%	99%
3	87 to 106	74%	80%	99%	98%
4	107 to 121	72%	78%	99%	97%
5	122 to 137	81%	85%	99%	98%
6	138 to 157	73%	80%	99%	97%
7	158 to 177	71%	75%	97%	95%
8	178 to 193	80%	79%	98%	97%
9	194 to 220	85%	87%	98%	100%
10	221 to 232	80%	95%	97%	100%
11	233 to 240	85%	93%	97%	99%
12	247 to 262	74%	82%	98%	98%
13	275 to 284	78%	87%	97%	99%
14	285 to 296	80%	81%	97%	99%
15	297 to 305	75%	80%	98%	99%

Table 3.5 shows that the nitrogen balances obtained are 97% or higher indicating that insofar as the nitrogen parameters are concerned, the systems were operated correctly and samples analysed accurately. However the COD balances obtained are comparatively poor ie averaging about 80%. Low COD balances have been observed before in cases where large anoxic mass fractions are included in a system; Arkley and Marais (1981) reported declining COD balances with increasing unaerated mass fractions; COD mass balance percentages of 77% were obtained when pre-denitrification (MLE) systems with anoxic mass fractions of 70% were considered. In work on intermittent aeration systems with large anoxic mass fractions (70%), Warburton et al (1991) also found that COD mass balances were low (80%) at a 20 day sludge age and declined further as sludge age decreased. The values obtained in this investigation are also in this range.

It is difficult to advance an explanation for the low COD balances. It is unlikely that the error lies in operation of the systems because good N balances were achieved. It is possible that some of the assumptions made in the COD balance such as the stoichometric constants 4.57 and 2.86, do not apply to systems with large anoxic mass fractions.

3.5.2. Carbonaceous organic material degradation

The influent and effluent COD concentrations for both units were monitored on a daily basis, and the results are plotted in Figures 3.2(a) and 3.2(b).
In the activated sludge models developed at UCT (WRC, 1984) the influent COD may be broken down into biodegradable and unbiodegradable fractions. The biodegradable COD fraction comprises two subfractions - a readily biodegradable (RBCOD) fraction and a slowly biodegradable particulate (PBCOD) fraction. The readily biodegradable fraction (fbs) was determined from a cyclically fed system which was operated in the UCT laboratory for this specific purpose. This system was fed the same sewage as the two systems operated in this investigation, and from the method outlined by Ekama et al., (1986) and WRC (1984), the readily biodegradable COD fraction with respect to the biodegradable COD (fbs)was estimated to be 0.23. The remaining biodegradable COD fraction ie 0.77 is considered PBCOD, which gives rise to the second slow rate of denitrification K_2 in the anoxic reactor of the MLE system like those operated in this investigation. The RBCOD fraction is required to isolate the second rate of denitrification (K_2 due to PBCOD) from the fast rate (K_1 due to RBCOD) to check the possible inhibiting effect of the alum sludge on the K_2 denitrification rate. (See Section 3.5.7)

The unbiodegradable fraction of the influent COD also may be subdivided into two subfractions ie an unbiodegradable particulate fraction (fup), and an unbiodegradable soluble fraction (fus). The former (fup) becomes enmeshed in the sludge mass and adds to the MLVSS in the reactor and is removed from the system via the daily sludge wastage. In contrast the latter (fus) leaves the system as effluent COD. The steady state activated sludge model of Marais and Ekama (1976) (see also WRC, 1984), which was accepted in this thesis as the basis on which to evaluate the experimental results observed in this investigation, accepts that at long sludge ages all the biodegradable COD is utilised by the organisms, and the only source of COD in the filtered effluent samples is that attributable to the unbiodegradable soluble fraction (fus). Consequently from the measured filtered effluent COD concentration the unbiodegradable soluble COD fraction (fus) can be estimated.

The average measured influent and effluent COD masses, as well as the additional COD introduced to the Experimental system via alum sludge dosing over each steady state period are shown in Table 3.6. If both systems were treating the

COD CONCENTRATIONS FOR CONTROL AND EXPERIMENTAL SYSTEMS

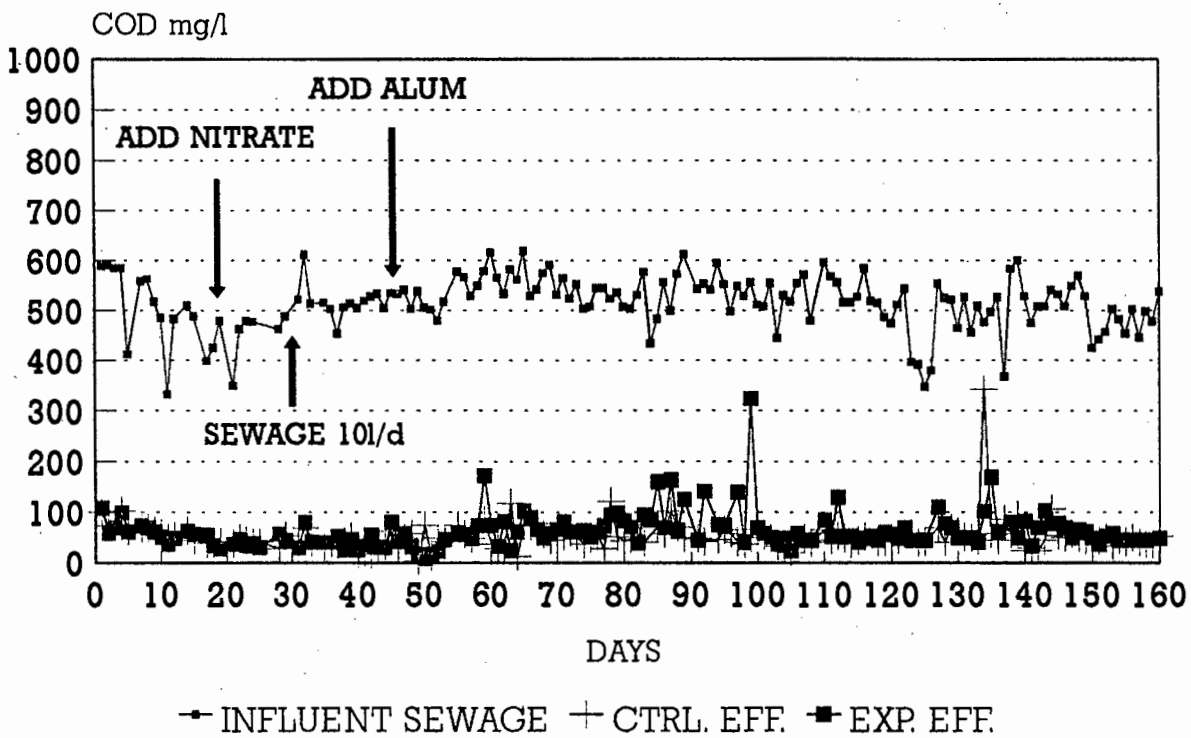


Figure 3.2(a)

COD CONCENTRATIONS FOR CONTROL AND EXPERIMENTAL SYSTEMS

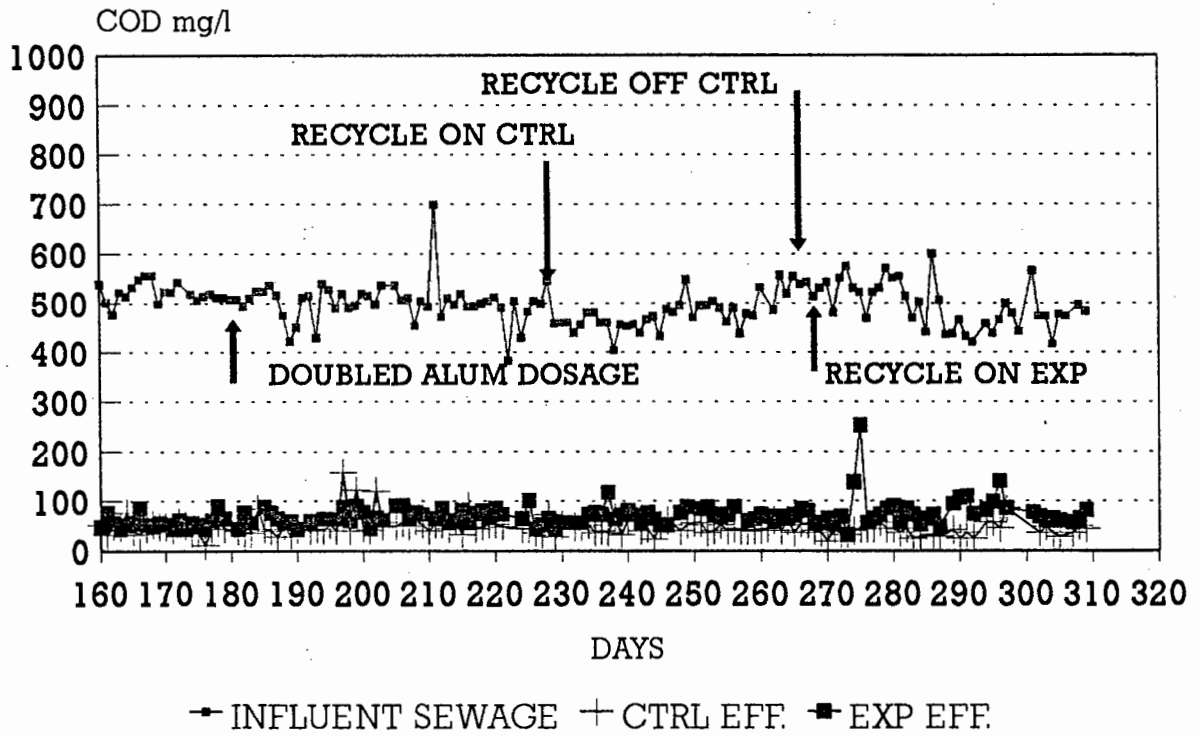


Figure 3.2(b)

same sewage only then it is reasonable to expect that the mass of COD in both systems' effluent is the same. However the mass of COD in the Experimental system throughout the investigation was higher than that in the Control system. Consequently it appears that the alum sludge must have contributed to the filtered effluent COD of the Experimental system. The mass of soluble effluent COD contributed by the alum sludge was calculated as follows:

The ratio of the control system's effluent COD mass to influent sewage COD mass gives the fus value for the sewage. The difference between the mass of effluent COD from the Experimental and Control systems is the COD mass due to the addition of alum sludge to the Experimental system. The fraction of the alum sludge COD that escapes with the effluent as soluble unbiodegradable COD is the ratio between the mass of COD in the effluent due to alum sludge addition and the mass of COD of the alum dosed. This fraction, denoted fus also for the alum sludge, was calculated for each steady state period and is listed in Table 3.6 and has an average value of 0.51. From this it appears that about 50% of the alum sludge COD escapes with the effluent as soluble unbiodegradable COD.

Table 3.6 : **Average measured daily effluent, influent and alum dose COD masses.**

Steady state period No	Period day No	Inf. sewage COD mass mgCOD/d	Alum dose COD mass mgCOD/d	Effluent mgCOD/d		Increase in COD effluent mass ex Exp mgCOD/d	Calculated fus	
				Ctrl	Exp		sewage	alum
1	59 -73	5640	353	617	798	181	0.11	0.51
2	74 -86	5200	353	614	881	267	0.12	0.76
3	87 -106	5380	266	549	999	450	0.10	-
4	107-121	5300	219	513	639	126	0.09	0.58
5	122-137	4680	219	603	761	158	0.13	0.72
6	138-157	5070	219	534	651	117	0.11	0.53
7	158-177	5190	219	477	595	118	0.09	0.54
8	178-193	4970	361	482	709	227	0.10	0.63
9	194-220	5050	439	651	781	130	0.13	0.30
10	221-232	4720	439	500	681	181	0.11	0.41
11	233-240	4570	583	516	662	146	0.11	0.25
12	247-262	4900	583	504	843	339	0.10	0.58
13	275-284	5210	539	457	1004	547	0.09	-
14	285-296	4640	1167	421	1030	609	0.09	0.52
15	297-305	4790	1167	507	795	288	0.11	0.25
mean			475			259	0.106	0.51

3.5.3 Volatile Suspended Solids

The measured VSS concentrations for the two systems during the investigation are shown plotted in Figures 3.3(a) and (b). The VSS mass, MXv, measured in activated sludge plants treating sewage comprises three components, an active, MXa, an endogenous residue, MXe, and an inert volatile mass, MXi. The inert component MXi arises from the unbiodegradable particulate COD fraction (fup) of the sewage and the magnitude of MXi is directly proportional to the fup fraction in the sewage. In order to determine the proportion of VSS of the dosed alum sludge that remains enmeshed in the activated sludge, the fup fraction of the sewage needs to be known. This was calculated with the aid of the steady state activated sludge theory of Marais and Ekama (1976) (see also WRC, 1984) as follows:

The total mass of VSS in the reactor is given by

$$MXv = MSti[[Yh \times Rs \times (1-fup-fus)]/(1+bh \times Rs)][1+f \times bh \times Rs] + (fup \times Rs)/fcv)$$

where

Yh = yield coefficient
= 0,45 mgVSS/mgCOD

Rs = sludge age (d)

bh = endogenous respiration rate
= 0,24/d at 20°C

f = unbiodegradable fraction of the active VSS (endogenous residue)
= 0,20

fcv = COD/VSS ratio of the sludge
= 1,48 mgCOD/mgVSS for the Control system

The value of fup was found by substituting the known values of the kinetic parameters (Yh, fcv, bh, and f) and the measured values for MXv, MSti and Rs for the Control system, as well the value of fus for the sewage calculated in Section 3.5.2 above. The calculated values of fup over each steady state period are given in Table 3.7.

MLVSS CONCENTRATIONS FOR CONTROL AND EXPERIMENTAL SYSTEMS

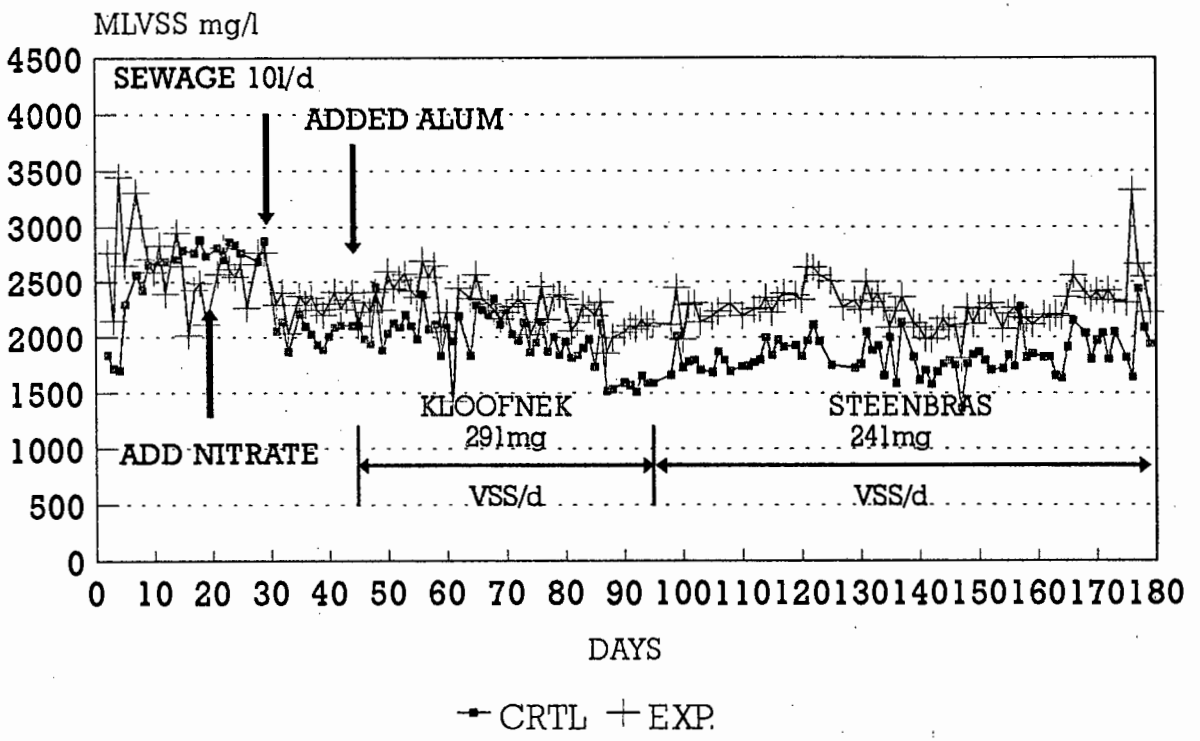


Figure 3.3(a)

MLVSS CONCENTRATIONS FOR CONTROL AND EXPERIMENTAL SYSTEMS

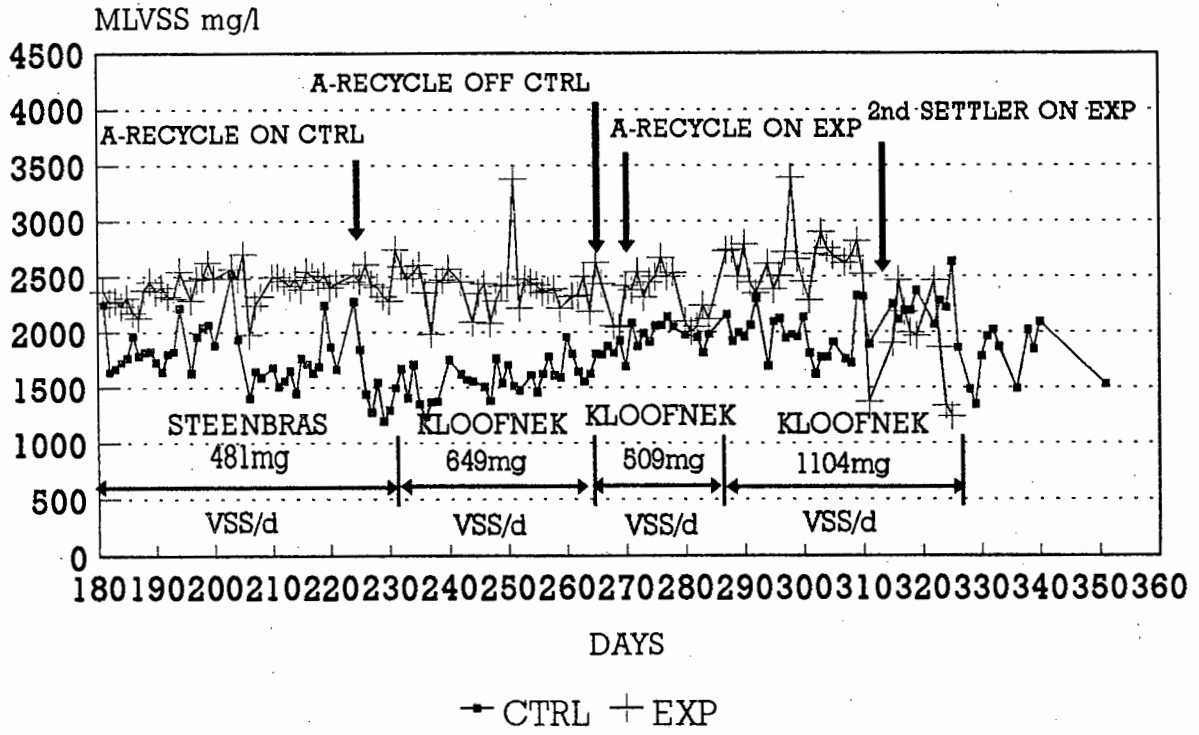


Figure 3.3(b)

Knowing fup, the active mass MXa can be calculated from the following equation:

$$MXa = MSti \times (1-fus-fup)Yh \times Rs/(1+bh \times Rs)$$

and knowing M(Xa), the active fraction of the measured VSS fav is given by

$$fav = MXa/MXv$$

Table 3.7: **Measured and predicted VSS concentrations**

Steady state period No	Period. Day No.	Measured VSS in Control system mgVSS/l	Measured VSS in Exp. system mgVSS/l	VSS predicted by steady state equ mgVSS/l	fup used in predicting VSS conc.	fav
1	59 -73	2107	2234	2105	0.098	0.329
2	74 -86	1926	2241	1927	0.067	0.340
3	87 -106	1674	2137	1675	0.036	0.430
4	107-121	1846	2336	1844	0.068	0.376
5	122-137	1878	2364	1875	0.130	0.286
6	138-157	1757	2131	1760	0.073	0.365
7	158-177	1898	2385	1893	0.084	0.351
8	178-193	1833	2321	1830	0.099	0.338
9	194-220	1841	2452	1822	0.086	0.338
10	221-232	1572	2484	1573	0.054	0.396
11	233-240	1457	2432	1457	0.046	0.407
12	247-262	1630	2412	1552	0.041	0.418
13	275-284	2006	2303	2004	0.103	0.350
14	285-296	2036	2566	2037	0.155	0.286
15	297-305	1880	2729	1878	0.133	0.291

In calculating the proportion of the dosed alum VSS that accumulates in the reactor it was accepted that because both systems received the same sewage the fup value for the Control and Experimental systems would be the same. Consequently the VSS difference between the Control and Experimental systems is the VSS contributed by the alum sludge. The proportion of the dosed alum sludge VSS that accumulates in the reactor was found from the difference between the VSS masses wasted daily from the Experimental and Control systems divided by the VSS dosed daily with the alum sludge. The results of these calculations are given in Table 3.8

Table 3.8: **Stoichiometric Relation between alum VSS added and measured and increase in VSS mass wasted from the Experimental system.**

Steady state period No	Period Day No	VSS mass* wasted from Ctrl. mgVSS/d	VSS mass* wasted from Exp mgVSS/d	Diff. in VSS mass wasted in Ctrl &Exp mgVSS/d (A)	VSS added via alum sludge mgVSS/d (B)	Ratio VSS diff/ alum. VSS add
1	59 -73	1054	1117	64	291	0.22
2	74 -86	963	1121	158	291	0.54
3	87 -106	837	1069	232	272	0.85
4	107-121	932	1168	236	241	0.98
5	122-137	939	1182	243	241	1.01
6	138-157	879	1066	187	241	0.78
7	158-177	949	1193	244	241	1.01
8	178-193	917	1161	244	417	0.59
9	194-220	921	1226	305	481	0.63
10	221-232	786	1242	456	481	0.95
11	233-240	729	1216	487	649	0.75
12	247-262	815	1206	391	649	0.60
13	275-284	1003	1152	149	509	0.29
14	285-296	1018	1283	265	1104	0.24
15	297-305	940	1365	425	1104	0.39

* Calculated from the measured VSS concentration listed in Table 3.7 times the volume of the system (10 l) divided by the sludge age (20 days).

The data in Table 3.8 giving the mass of VSS dosed daily with the alum sludge (column B) and the increased VSS mass wasted from the Experimental system (column A) are presented graphically in Figure 3.4. It can be seen in Fig 3.4 that it took about 30 days (day 59 to 86) before the increased mass of VSS wasted equalled the VSS dosed via the alum sludge (hatched area reaches same height as solid line in Fig 3.4). At the low alum dosage rate (241mgISS/d), the daily additional VSS added via alum sludge and the increased VSS wasted remained approximately equal for 90 days (day 87 to 177, steady state periods 3 to 7). This equality of alum VSS in and out indicates that the VSS material was not biodegradable.

This was the only occasion where steady state between input alum VSS and output alum VSS was achieved (see Fig 3.4) except for a brief period between days 221 and 232 (steady state period 10) at the higher dose rate 481mgISS/d;

DAILY ALUM VSS DOSE AND ADDITIONAL VSS WASTED FROM EXPERIMENTAL SYSTEM

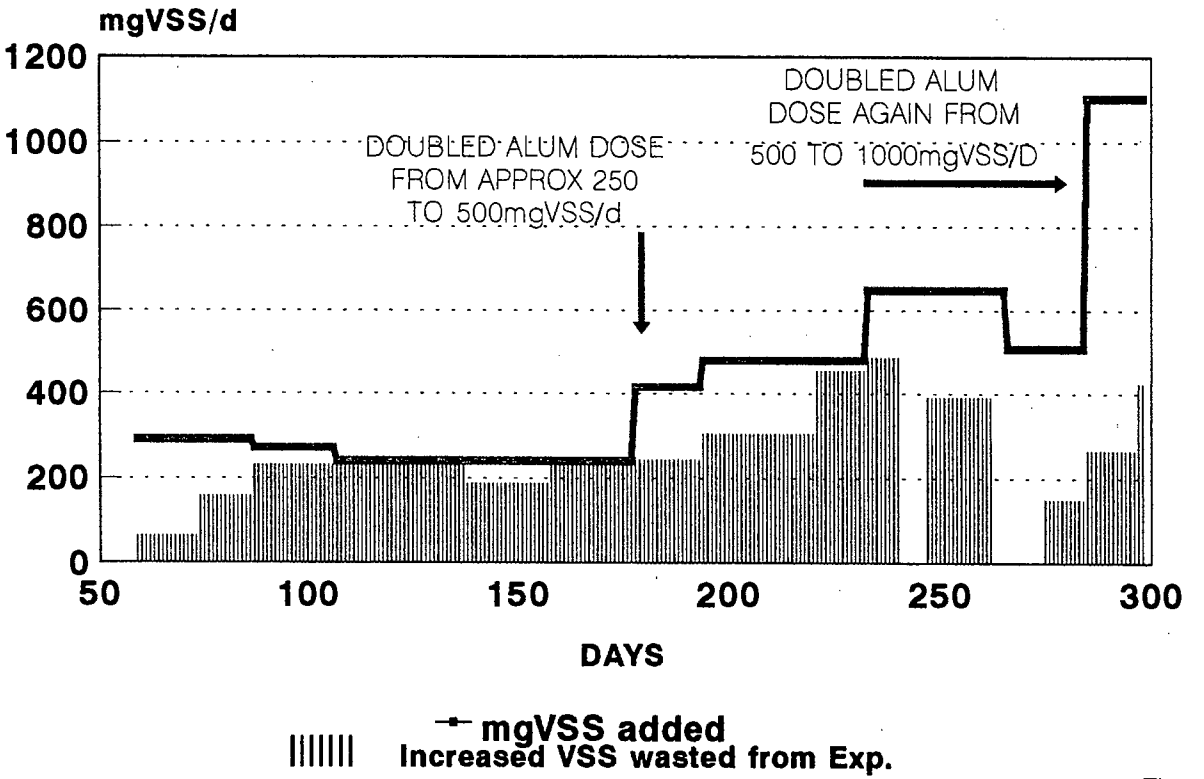


Figure 3.4

after increasing the alum dose on day 178, the system took almost 7 weeks (46 days, or about 2,5 sludge ages, periods 8 and 9) to find steady state, and almost as soon as it had, the dosage was increased again. Thereafter, the system never achieved steady state again between the alum VSS dosed and the extra VSS wasted. It was concluded from Fig 3.4 that the VSS of the alum sludge is not biodegradable and given sufficient time to achieve steady state, the VSS mass added daily with the alum sludge will equal the the additional VSS mass taken from the system via the sludge wastage.

3.5.4. Inorganic Suspended Solids

The ISS mass wasted is the difference between the TSS and VSS mass wasted daily. The mass of ISS wasted daily from the two systems, the increased ISS mass wasted from the Experimental system ie the difference between the ISS wasted from each system are listed in Table 3.9. The ISS added in the alum sludge dose and the ratio additional ISS wasted from the Experimental system/ISS added in alum dose are also listed.

Table 3.9: **Stoichiometric relation between alum ISS added and increase in ISS mass wasted from Experimental system.**

Steady state period No	Period Day No	ISS mass wasted from Ctrl. mgISS/d	ISS mass wasted from Exp. sys mgISS/d	Difference in ISS mass wasted in Ctrl. & Exp mgISS/d	ISS added via alum sludge mgISS/d	Ratio ISS diff/ alum. ISS add
1	59 -73	183	319	136	173	0.79
2	74 -86	153	340	187	173	1.08
3	87 -106	139	357	218	189	1.15
4	107-121	136	400	264	212	1.25
5	122-137	140	414	274	212	1.29
6	138-157	149	378	229	212	1.08
7	158-177	151	438	287	212	1.35
8	178-193	166	473	307	415	0.74
9	194-220	137	562	425	424	1.00
10	221-232	142	628	486	424	1.15
11	233-240	132	608	476	227	2.10
12	247-262	175	498	323	227	1.42
13	275-284	115	400	285	226	1.26
14	285-296	160	635	475	491	0.97
15	297-305	160	499	339	491	0.69

Although similar trends in the accumulation of the VSS and ISS were observed, it can be seen from Table 3.9 that the ratio ISS difference / alum ISS added (last column) increases above 1,0 indicating that more ISS is wasted from the system than added via the alum sludge dose. This is due to the precipitation of $AlPO_4$. It was accepted ealier that the inorganic (ISS) part of the alum sludge prior to incineration was $Al(OH)_3$ (MM = 78g/mol). When the hydroxide ions are exchanged with phosphate to form the $AlPO_4$ precipitate (MM = 122g/mol), there is an increase of (122-78)/31 = 1.42 mg ISS/mgP precipitated. This additional ISS adds to the reactor ISS concentration. During the first 7 steady state periods when the alum dosage was around 450mgTSS/d the additional P removal attributable to this was about 30mgP/d (3mgP/l) thereby increasing the ISS in the reactor by 43mgISS.

Taking averages over steady periods 3 to 7 during which the alum sludge VSS added and additional VSS wasted from the Experimental system were approximately equal and therefore at steady state, the average ISS wasted was 263 mg/day. Subtracting from this the 43 mg ISS/day $AlPO_4$ precipitate formed, gives 220 mg ISS/day. This very closely equals the 212 mg ISS added via the alum sludge. These calculations demonstrate that the ion exchange between the hydroxide and phosphate contributes negliglibly (<10%) to the increase in ISS from the alum dosage, and that the major contributor to the increase in ISS in the Experimental system, is the ISS in the alum sludge itself.

3.5.5 Total Suspended Solids

The Total Suspended Solids concentration measured daily in the Control and Experimental systems during the study, are shown in Figures 3.5(a) & 3.5(b).

The proportion of the dosed alum TSS that accumulates in the reactor was calculated in the same way as that of the VSS discussed in Section 3.5.3 and the results are given in Table 3.10. It can be seen from this table that the same trends arise in the TSS as did in the ISS, i.e. there is an the increase in the TSS mass in the Experimental system above as the TSS dosed in the alum sludge, provided sufficient time is allowed for steady state conditions to be established. This increase arises from the increase in ISS due to $AlPO_4$ precipitation as discussed in Section 3.5.4. The percentage increase in TSS due to the increase in ISS is very low (<5%), because the alum TSS includes the VSS (about 50% VSS) and the VSS remains unchanged through the system, (see Section 3.5.3).

MLSS CONCENTRATIONS FOR CONTROL AND EXPERIMENTAL SYSTEMS

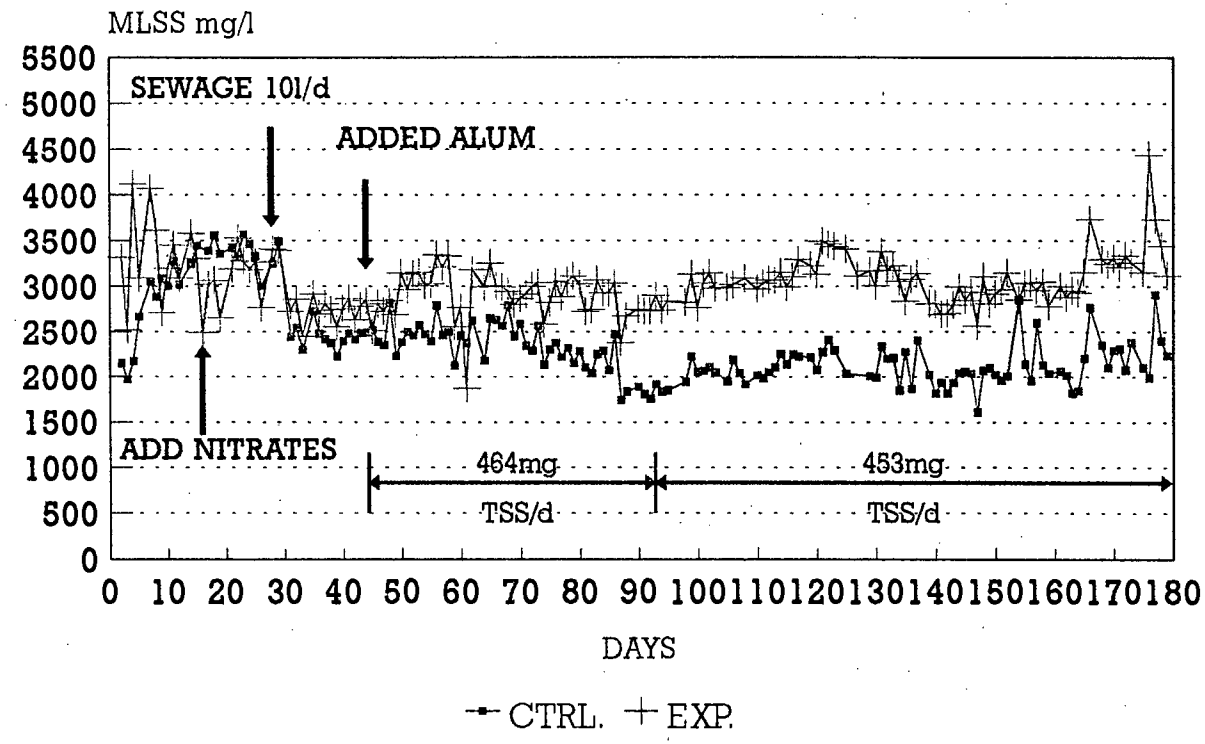


Figure 3.5(a)

MLSS CONCENTRATIONS FOR CONTROL AND EXPERIMENTAL SYSTEMS

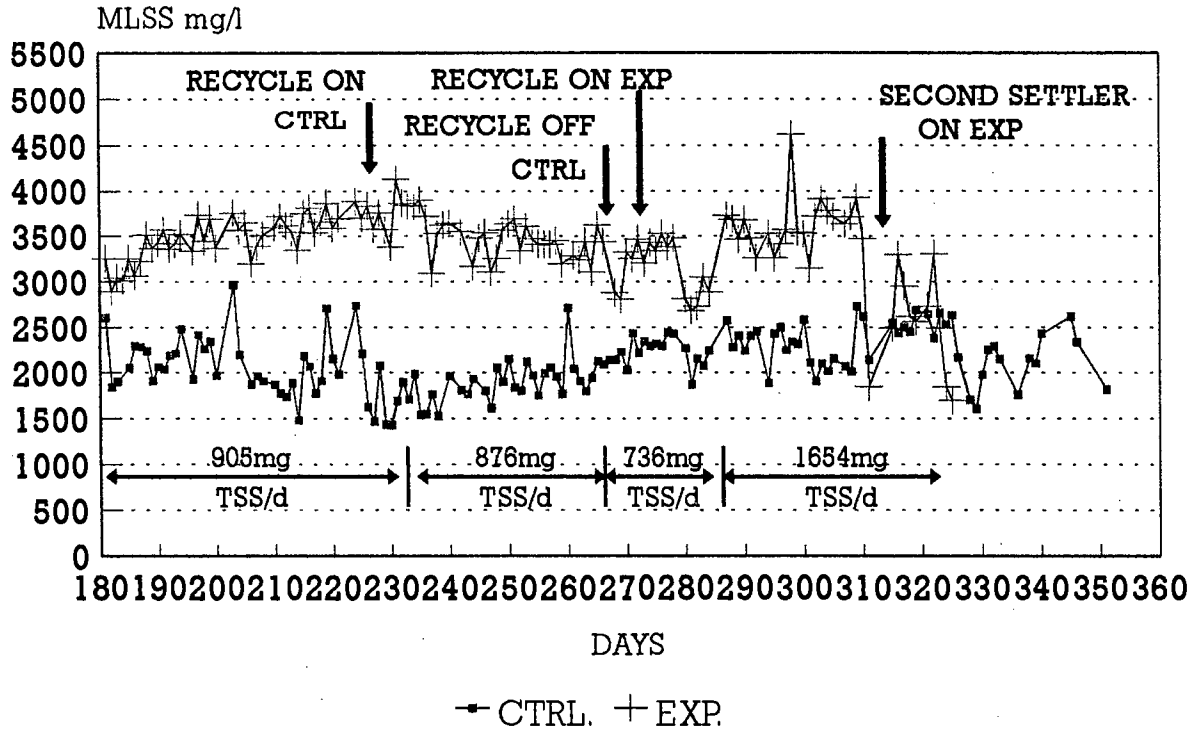


Figure 3.5(b)

Table 3.10: **Stoichiometric relation between alum TSS added and increase in TSS mass wasted from Experimental system.**

Steady state period No	Period Day No	TSS mass wasted from Ctrl. mgTSS/d	TSS mass wasted from Exp. mgTSS/d	Difference in TSS mass wasted in Ctrl. & Exp mgTSS/d	TSS added via alum sludge mgTSS/d	Ratio TSS diff/ alum. TSS add
1	59 -73	1237	1436	199	464	0.43
2	74 -86	1116	1460	344	464	0.74
3	87 -106	976	1426	450	434	1.04
4	107-121	1059	1568	509	453	1.12
5	122-137	1079	1596	517	453	1.14
6	138-157	1027	1444	417	453	0.92
7	158-177	1100	1631	531	453	1.17
8	178-193	1083	1634	551	884	0.62
9	194-220	1058	1788	730	905	0.81
10	221-232	928	1870	942	905	1.04
11	233-240	861	1824	963	876	1.10
12	247-262	990	1704	714	876	0.82
13	275-284	1118	1552	434	736	0.59
14	285-296	1178	1918	740	1654	0.45
15	297-305	1100	1864	764	1654	0.46

3.5.6 Nitrification and oxygen required for nitrification

Graphs of the daily influent and effluent TKN concentrations are plotted in Figs 3.6.(a) & (b). It can be seen that during the start up period, days 1 to 10, that nitrification in both systems was not yet complete. After day 11 complete nitrification was achieved and maintained throughout the investigation which is reflected in the low effluent TKN concentrations.

The effluent TKN concentrations for the two systems were very similiar for the duration of the study. The contribution to the TKN load on the Experimental system by the addition of alum sludge is mimimal when compared to the TKN of the waste water; this contribution being in the order of 2.7% of the total TKN passing through the system daily.(Table 3.11)

The daily mass of influent TKN in the sewage and alum sludge, the mass of TKN in the effluent and the increase/decrease in the TKN mass in the Experimental system are listed in Table 3.11.

TKN CONCENTRATIONS FOR CONTROL AND EXPERIMENTAL SYSTEMS

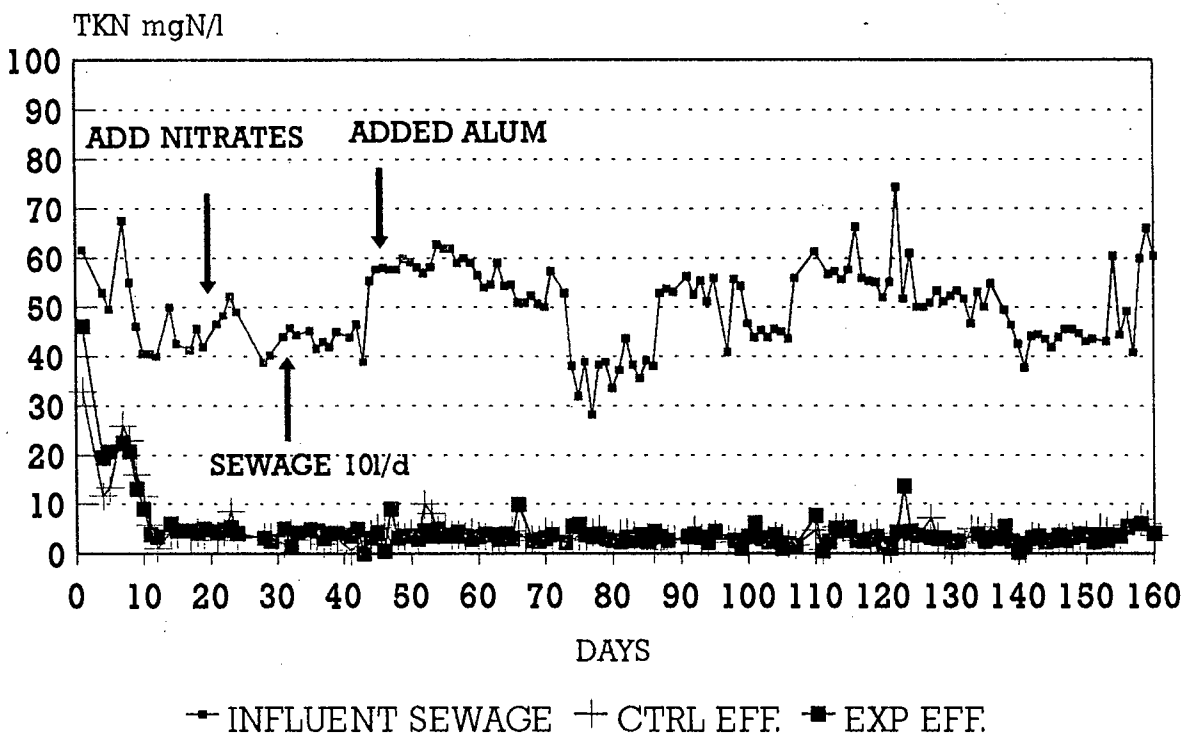


Figure 3.6(a)

TKN CONCENTRATIONS FOR CONTROL AND EXPERIMENTAL SYSTEMS

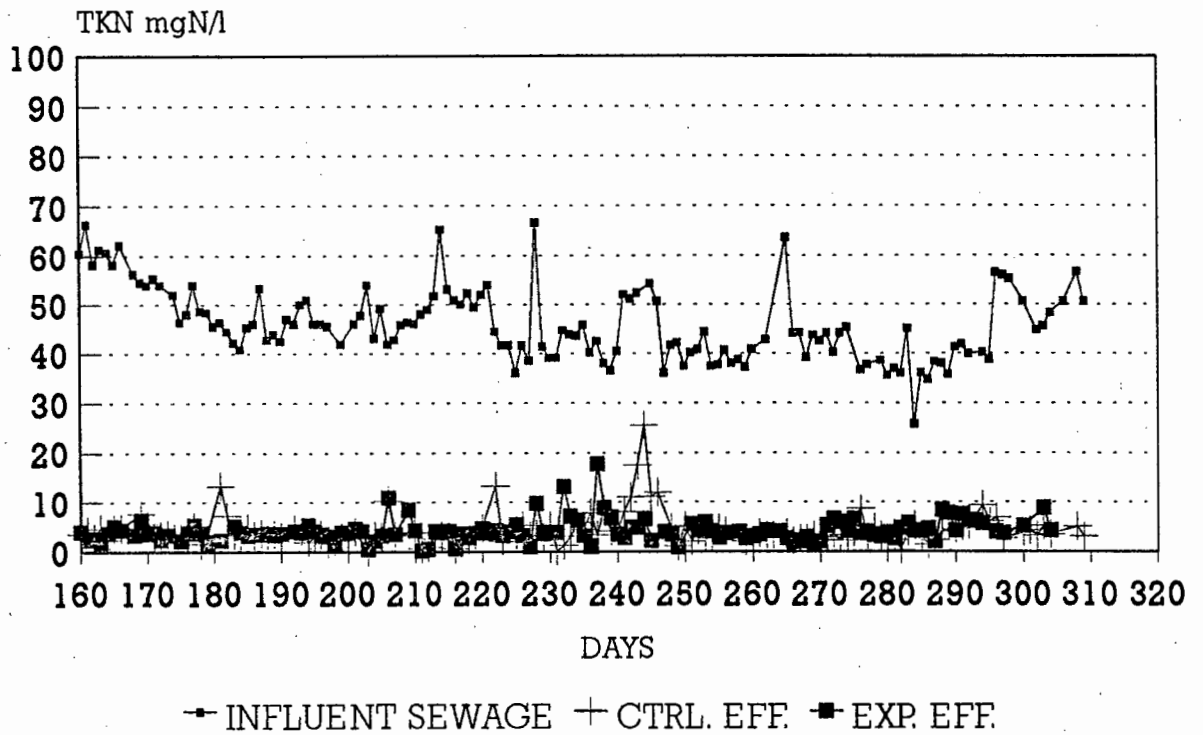


Figure 3.6(b)

Table 3.11: **Influent, dosed alum and effluent TKN masses.**

Steady state period	Period Day No.	Sewage Load mgN/d	Alum load mgN/d	Effluent masses		Increase in mass in Exp sys
				Ctrl. mgN/d	Exp. mgN/d	
1	59 -73	541	1.2	36	41	5
2	74 -86	369	1.2	36	40	4
3	87 -106	498	2.0	30	34	4
4	107 -121	571	2.4	36	35	-1
5	122 -137	537	2.4	38	44	6
6	138 -157	450	2.4	34	34	0
7	158 -177	571	2.4	46	41	-5
8	178 -193	459	4.0	49	38	-11
9	194 -220	480	4.7	36	40	4
10	221 -232	441	4.7	49	54	5
11	233 -240	415	7.6	57	76	19
12	247 -262	398	7.6	37	43	6
13	275 -284	378	4.4	42	49	7
14	285 -296	402	9.6	53	64	11
15	297 -305	501	9.6	41	109	68

Table 3.11 indicates that in general the mass of TKN in the Experimental system's effluent was higher than that from the Control system but negligibly so. From this it can be concluded that unlike the COD, the TKN in the alum sludge does not influence the TKN of the effluent, probably mainly because there is so little TKN in the alum sludge.

The nitrification capacity MNc ie the mass of nitrate generated by nitrification, was determined in the nitrogen balance calculations discussed in Section 3.5.1. The results for the Control and Experimental systems for the steady state periods are listed in Table 3.12.

The mass of oxygen required for nitrification,(MOn), is simply the mass nitrification capacity MNc multiplied by the stoichiometric value 4.57mgO/mgNO_3-N generated.

Table 3.12: **Nitrification capacity and nitrification oxygen demand**

Steady state period No	Period Day No	Nitrification Capacity MNc (mgNO3-N/d)		Oxygen demand for nitrification MOn mgO/d	
		Ctrl.	Exp.	Ctrl.	Exp.
1	59 -73	399.6	395.1	1826	1806
2	74 -86	239.7	232.7	1095	1063
3	87 -106	389.5	377.3	1780	1724
4	107-121	449.8	442.6	2056	2023
5	122-137	409.1	394.9	1870	1805
6	138-157	330.1	328.9	1509	1503
7	158-177	430.1	434.6	1966	1986
8	178-193	318.3	331.0	1455	1513
9	194-220	353.0	346.6	1613	1584
10	221-232	313.4	304.8	1432	1393
11	233-240	285.1	267.6	1303	1223
12	247-262	283.3	279.4	1295	1277
13	275-284	235.7	232.6	1077	1063
14	285-296	247.2	243.7	1130	1114
15	297-305	366.0	303.3	1673	1386

The values obtained for the two systems in Table 3.12 are very similiar due to the small amount of nitrogen added in the alum sludge, of which an insignificant amount is biodegradable. The closeness of the results obtained from both systems also shows that alum sludge addition has no detrimental effect on the vitality of the nitrifying organisms.

3.5.7. Denitrification

The measured effluent nitrate values are plotted in Figures 3.7(a) and (b). The addition of nitrate to the anoxic reactor of the laboratory systems ensured that there was always nitrate leaving this reactor, with the result that the nitrate load on the completely mixed anoxic reactors was greater than their denitrification potential. Under these conditions the denitrfication potential, Dp1, is merely the mass of nitrate removed from the system daily. The denitrification measured in the MLE laboratory systems is due to two simultaneous denitrification reactions, viz a fast rate (K_1) due to influent RBCOD utilization and a slower background rate (K_2) due to influent PBCOD utilization. It is not possible to measure the rates separately in a completely mixed anoxic reactor like those of the Control and Experimental systems, but it is possible to estimate the contribution by the two reactions to the total measured mass of nitrate removed.

EFFLUENT NITRATE CONCENTRATIONS FROM CONTROL AND EXPERIMENTAL SYSTEMS

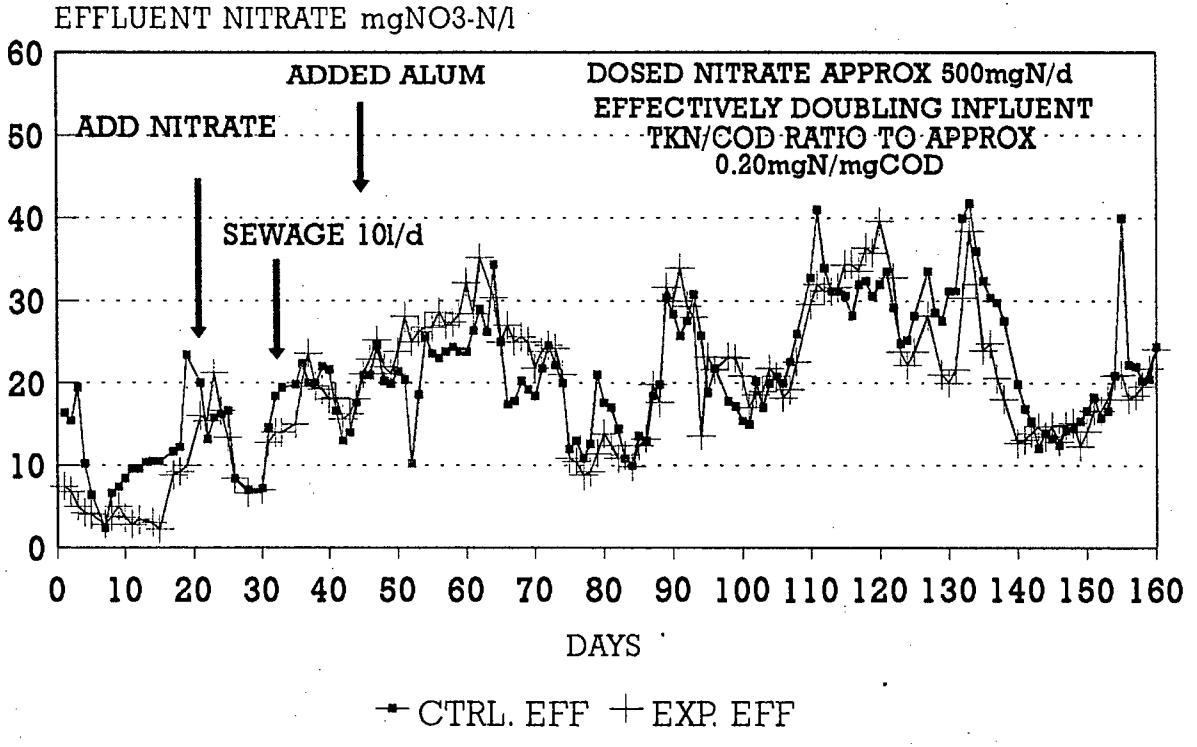


Figure 3.7(a)

EFFLUENT NITRATE CONCENTRATIONS FROM CONTROL AND EXPERIMENTAL SYSTEMS

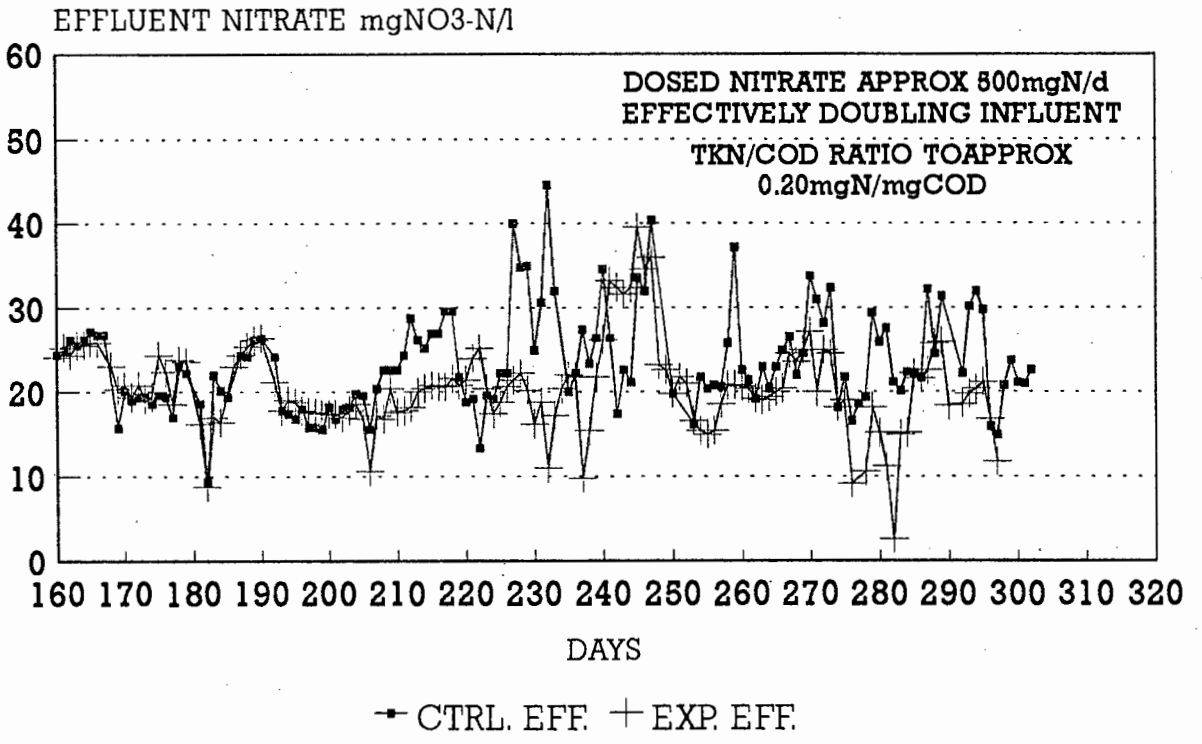


Figure 3.7(b)

To do this the RBCOD fraction needs to be known so that the mass of nitrate removed by the first rate K_1 can be calculated. Then because nitrate was not limited the contribution of the second rate K_2 is simply the difference between the total nitrate mass removed and that removed by the first rate K_1. Knowing the mass of nitrate removed by the second slow rate enables this rate, K_2, to be calculated. This calculation procedure is outlined below:

Denitrification potential(Dp1) ($mgNO_3$-N/d)

= $Dp1_{K1}$ + $Dp1_{K2}$
= Mass of nitrate removed M(Nnd)
= mass of nitrate fed into system + mass of nitrate generated from TKN - mass of nitrate in the effluent

where

$Dp1_{K1}$, the denitrification by the first rate K_1
= the mass of nitrate removed by the utilization of RBCOD
= MSbi x (fbs(1-fcv x Yh)/2,86) ($mgNO_3$-N/d)

$Dp1_{K2}$, the denitrification by the second rate K_2
= the mass of nitrate removed by the utilization of PBCOD
= MSbi x (K_2 x f_{xl} x Yh x Rs/(1+bh x Rs)) ($mgNO_3$-N/d)

MSbi = the mass of biodegradable COD in the influent sewage
= MSti x (1-fup -fus) (mgCOD/d)

f_{xl} = anoxic mass fraction
= 0,7 for the Control and Experimental systems

The denitrification potential as well as the calculated rate K_2 determined from the measured data are listed in Table 3.13 for the Control and Experimental systems.

In order to calculate $Dp1_{K1}$, a value for influent RBCOD fraction, fbs is needed. The fbs value was measured in a cyclically fed system receiving the same sewage as the laboratory systems and was found to have an average value of 0.23 during the investigation. As the alum sludge did not have a RBCOD fraction the nitrate denitrified by the first rate K_1 is the same in both the Experimental and Control systems.

Table 3.13: Denitrification Potentials and K_2 denitrification rates for the Control and Experimental systems.

Steady state period No.	Period Day No.	Sbi load due to sewage. mgCOD/d	Mass NO3 denitrified Dp1 mgNO3-N/d		DpK1 mgNO3 -N/d fbs= 0.23	K2 $mgNO_3$- & N/(mgAVSS.d)	
			Ctrl	Exp		Ctrl	Exp
1	59 -73	4467	583.6	599.1	120	0.096	0.099
2	74 -86	4228	563.3	525.7	114	0.098	0.090
3	86 -106	4648	623.5	600.3	125	0.099	0.094
4	107-121	4463	620.8	573.7	120	0.103	0.095
5	122-137	3463	579.1	526.9	93	0.129	0.115
6	138-157	4142	556.1	528.9	111	0.099	0.093
7	158-177	4287	566.8	573.6	115	0.097	0.098
8	178-193	3832	479.3	461.0	103	0.090	0.086
9	194-220	4060	533.0	490.6	109	0.096	0.087
10	221-232	4040	458.4	513.8	109	0.094	0.092
11	233-240	3857	446.1	493.7	104	0.082	0.093
12	247-262	4209	502.3	520.4	113	0.085	0.089
13	275-284	4204	480.7	560.6	113	0.081	0.098
14	285-296	3503	434.2	457.7	94	0.089	0.096
15	297-305	3674	471.0	531.3	99	0.093	0.108

Average K_2 denitrification rates of 0.096 and 0.096 $mgNO_3$-N/(mgAVSS.d) for the Control and Experimental systems respectively are obtained from Table 3.13. These values compare favourably with the generally accepted value of 0.101 $mgNO_3$-N/(mgAVSS.d) (WRC, 1984), and indicates that denitrification is unaffected by alum sludge addition.

3.5.8 Total and carbonaceous oxygen demand

The total oxygen utilization rate was measured in the aerobic reactor of the Control and Experimental systems was measured 3 to 4 times daily over a 2 to 3 hour period. The results are shown plotted in Figures 3.8(a) and (b). From these results, the average daily OUR over a steady state period was calculated. This average OUR (mgO/l/hr) was multiplied by the volume of the aerobic reactor (3l) and 24 hours gives the average mass of oxygen consumed daily (MOtm).

OXYGEN UTILIZATION RATES FOR CONTROL AND EXPERIMENTAL SYSTEMS.

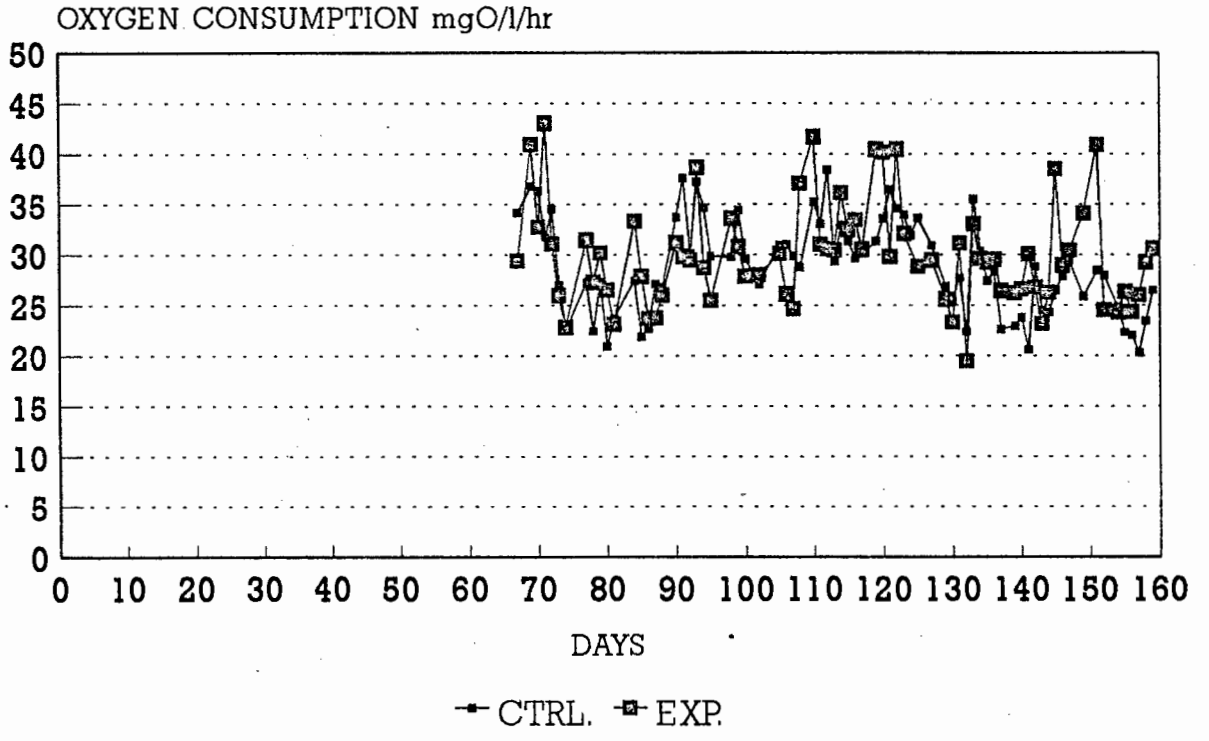


Figure 3.8(a)

OXYGEN UTILIZATION RATES FOR CONTROL AND EXPERIMENTAL SYSTEMS

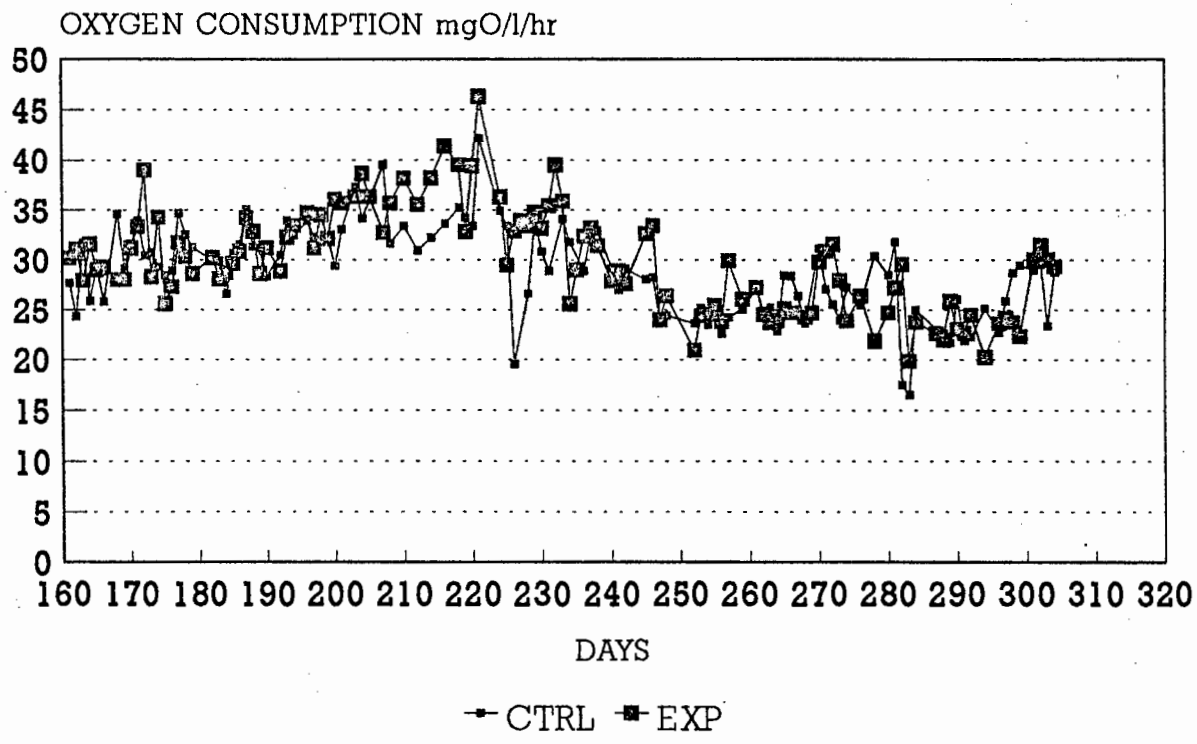


Figure 3.8(b)

The MOtm values for both systems in each steady state period are given in Table 3.14. To evaluate the effect of the alum sludge, the difference in MOtm between the Experimental and Control systems is given in Table 3.14.

The measured MOtm is the sum of the carbonaceous and nitrification oxygen demands. The mass of nitrate generated was calculated in the nitrogen balance (Section 3.5.1 above) and from this the mass of oxygen required for nitrification. Because the N balances are very good (>98%, Table 3.5) the calculated oxygen mass utilized for nitrification MOn are accurate. Subtracting MOn (see Table 3.12) from the measured MOtm, and adding the oxygen recovered in denitrification (2,86 * the mass of nitrate denitrified), gives the measured carbonaceous oxygen consumed MOc, which like MOtm, is given in Table 3.14. Also given in Table 3.14 is the difference between the Experimental and Control MOc values.

Table 3.14: **Measured total and carbonaceous oxygen demands**

Steady state period No.	Period day No	Total measured oxygen demand MOtm mgO/d		Incr/ decr. in Exp MOtm mgO/d	Carbonaceous oxygen demand MOc mgO/d		Incr/ decr. in Exp MOc mgO/d
		Crtl	Exp		Ctrl	Exp	
1	59 -73	2376	2448	+ 72	2219	2355	+136
2	74 -86	1728	1944	+216	2244	2385	+141
3	87 -106	2232	2088	-144	2235	2081	-154
4	107-121	2304	2448	+144	2023	2063	+ 40
5	122-137	2088	2088	0	1874	1790	- 84
6	138-157	1800	2088	+288	1881	2098	+217
7	158-177	2102	2174	+ 72	1757	1828	+ 71
8	178-193	2232	2160	- 72	2147	1965	-182
9	194-220	2376	2592	+216	2287	2411	+124
10	221-232	2232	2592	+360	2111	2668	+557
11	233-240	2304	2232	- 72	2277	2421	+144
12	247-262	1800	1814	+ 14	1941	2025	+ 84
13	275-284	1800	1786	- 14	2099	2326	+227
14	285-296	1656	1663	+ 7	1768	1858	+ 90
15	297-305	2016	1966	- 50	1690	2099	+409

The difference in total and carbonaceous oxygen consumption between the Control and Experimental systems is difficult to evaluate as no definite trend is noted in Table 3.14. It would seem from the absence of a discernable trend, that the effect of the additional COD load on the Experimental system had no effect on the the carbonaceous oxygen demand; more specifically over the last five

steady state periods which were the periods during which the greatest alum COD loads were dosed viz. days 233 to 384, 550mgCOD/d and days 285 to 305 approximately 1167mgCOD/d the carbonaceous oxygen consumption in the Experimental and Control units is very similiar. This indicated that the COD and/or VSS in the alum sludge is not biodegradable in the activated sludge system, and confirms the same conclusion made earlier after evaluating the VSS results.

3.5.9 Phosphorus Removal

The concentration of phosphorus in the influent and effluent was measured daily and these values are plotted in Figs 3.9(a) and (b). Initially (day 10 to 20) the P removal from both systems was quite high at 10mgP/l. During this time both systems probably were exhibiting biological excess P removal (BEPR) as a result of the initial poor nitrification and absence of nitrate dosing into the anoxic reactors leading to a low effluent nitrate concentration [See Figures 3.6(a) and 3.7(a)]. On day 18 a supplementary nitrate source was dosed into the anoxic reactors of both systems at a rate of 500mgN/d to prevent excess phosphorus removal from taking place so that the effects of alum sludge addition would not be masked by fluctuations in BEPR. After nitrate dosing commenced the P removal in both systems declined to around 3 to 4 mgP/l.

The concentration of phosphorus in the effluent from the Control and Experimental systems was very similiar for the first 44 days as expected because the systems were operated identically over this period. On day 45 alum sludge was added to the Experimental system. From day 50 the phosphorus concentration in the effluent from the Experimental system was noticeably lower than that of the Control system. The additional phosphorus removal measured in the Experimental system was attributed to alum sludge dosing. The alum sludge dose was expressed in terms of ISS added, for the reason described in Section 3.3 above. The mass of ISS in the alum sludge dosed daily, the influent and effluent phosphorus masses, the additional phosphorus mass removed in the Experimental system as given by the difference in the Control and Experimental system effluent masses, and the ratio between the additional phosphorus mass removed by the alum sludge and the daily alum ISS added are listed for each steady state period in Table 3.15.

PHOSPHORUS CONCENTRATIONS FOR CONTROL AND EXPERIMENTAL SYSTEMS

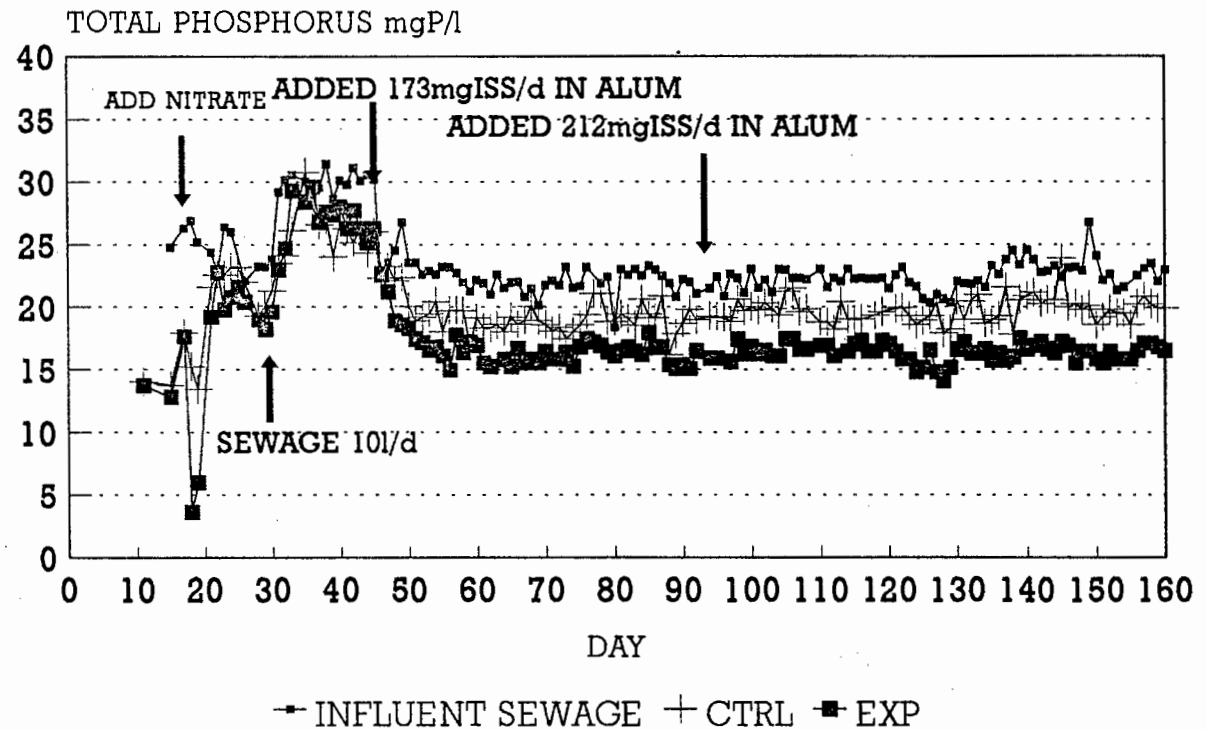


Figure 3.9(a)

PHOSPHORUS CONCENTRATIONS FOR CONTROL AND EXPERIMENTAL SYSTEMS

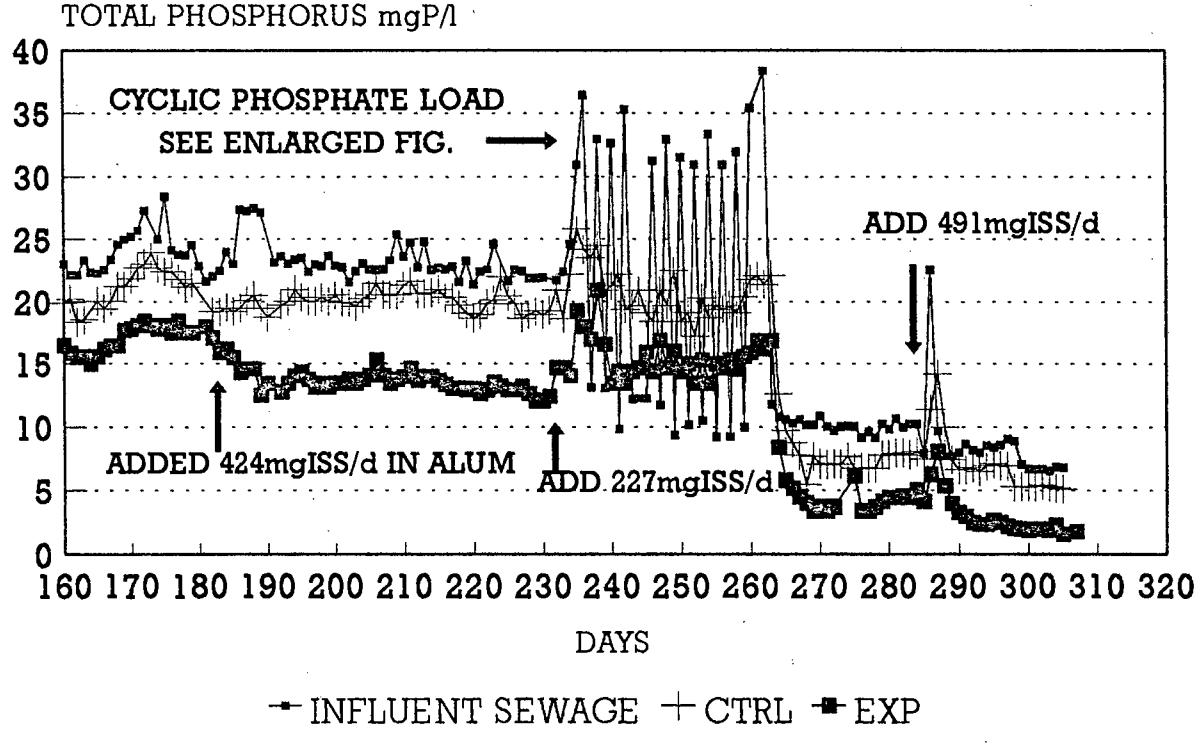


Figure 3.9(b)

Table 3.15: **Average measured daily effluent, influent, & additional phosphorus mass removal in Experimental system at a pH of 7.6, and additional P removed/alum ISS added ratios.**

Steady state period No	Period Day No.	Avg inf. P mass mgP/d	Effluent mgP/d.		Additional P removal in Exp. sys. mgP/d	Alum sludge ISS added mgISS/d	Ratio add P removed/ ISS added
			Ctrl. syst.	Exp. syst.			
1	59 -73	236	200	179	21	173	(0.121)
2	74 -86	244	213	184	29	173	0.168
3	87 -106	240	213	178	35	189	0.185
4	107-121	245	212	184	28	212	0.132
5	122-137	240	214	172	42	212	0.198
6	138-157	252	218	177	41	212	0.193
7	158-177	258	226	178	48	212	0.226
8	178-193	261	212	164	48	415	(0.116)
9	194-220	249	220	148	72	424	0.170
10	221-232	243	215	141	74	424	0.175
11	233-240	281	238	195	43	227	(0.189)
12	247-262	246	219	171	48	227	0.211
13	275-284	109	82	49	33	226	0.146
14	285-296	103	89	45	44	491	(0.090)
15	297-305	78	59	23	36	491	(0.073)

The additional P removal per alum ISS dosed in Table 3.15 can be seen to vary considerably ranging from 0.121 to 0.226 the reason for this is that it took a considerable period to achieve steady state between alum dosed and P removed. To assist in selecting steady state values of P removed/alum dosed, the daily mass of P removed (ie the difference between Experimental and Control system P removal) is plotted in Figure 3.10(a) and (b) together with the times of different alum dosages. From Figure 3.10 and Table 3.15 can be seen for example that over the first 7 steady state periods, during which the alum dosing was 173 to 212 mgISS/d it was only by the third steady period that the P removal seemed to level off at around 35mgP/d (3.5mgP/l). This is confirmed in Fig 3.4 with steady state between VSS dosed and wasted also only achieved after steady state period 3 (see Section 3.5.3). This effect can be noticed at each occasion the alum dose was increased and therefore care needed to be exercised in selecting the appropiate steady state values when assessing the P removal per mg alum ISS added.

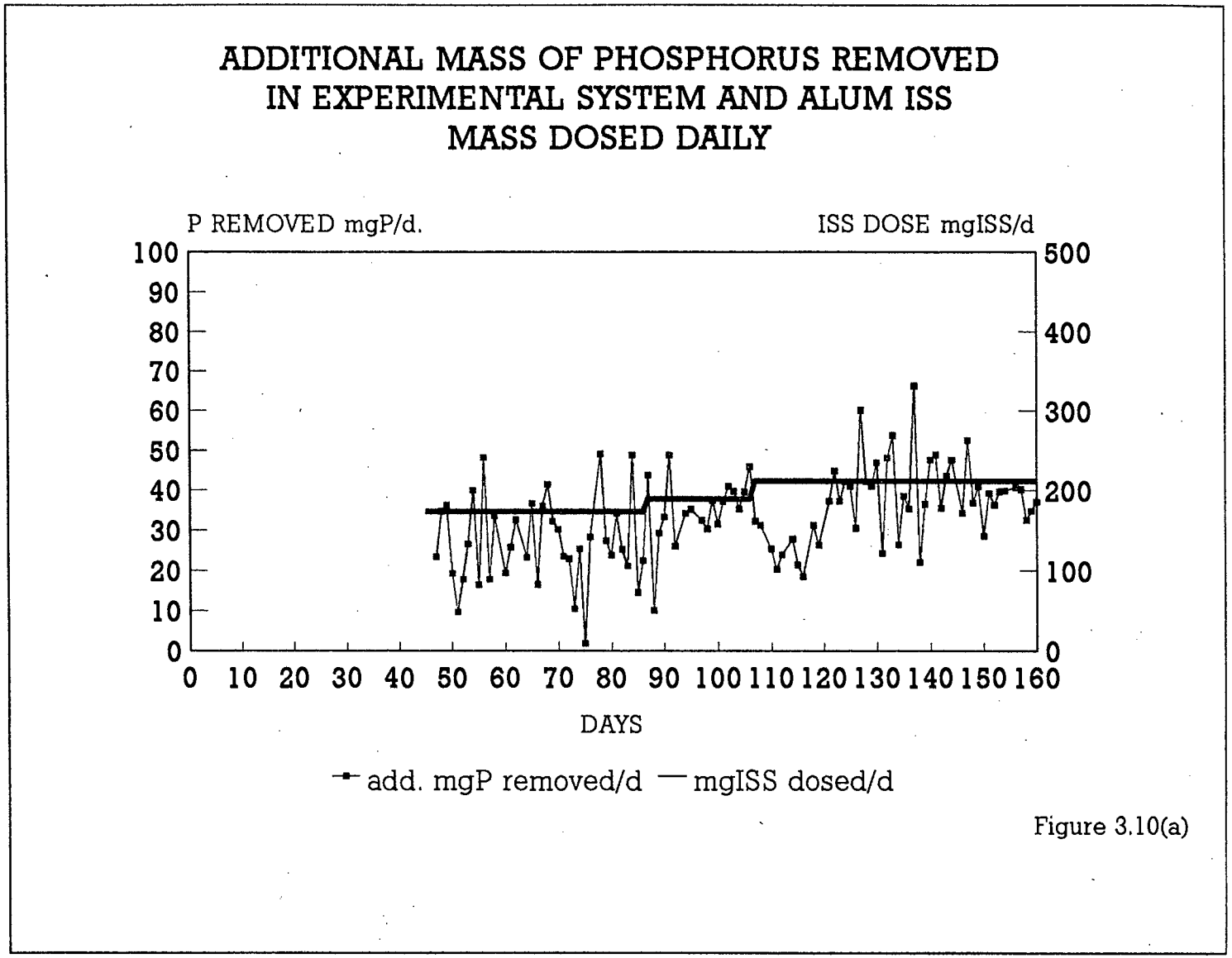

ADDITIONAL MASS OF PHOSPHORUS REMOVED
IN EXPERIMENTAL SYSTEM AND ALUM ISS
MASS DOSED DAILY
P REMOVED mgP/d.
ISS DOSE mgISS/d
100
90
80
70
60
50
40
30
20
10
0
500
400
300
200
100
0
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
DAYS
add. mgP removed/d
mgISS dosed/d

Figure 3.10(a)

ADDITIONAL MASS OF PHOSPHORUS REMOVED IN EXPERIMENTAL SYSTEM AND ALUM ISS MASS DOSED DAILY

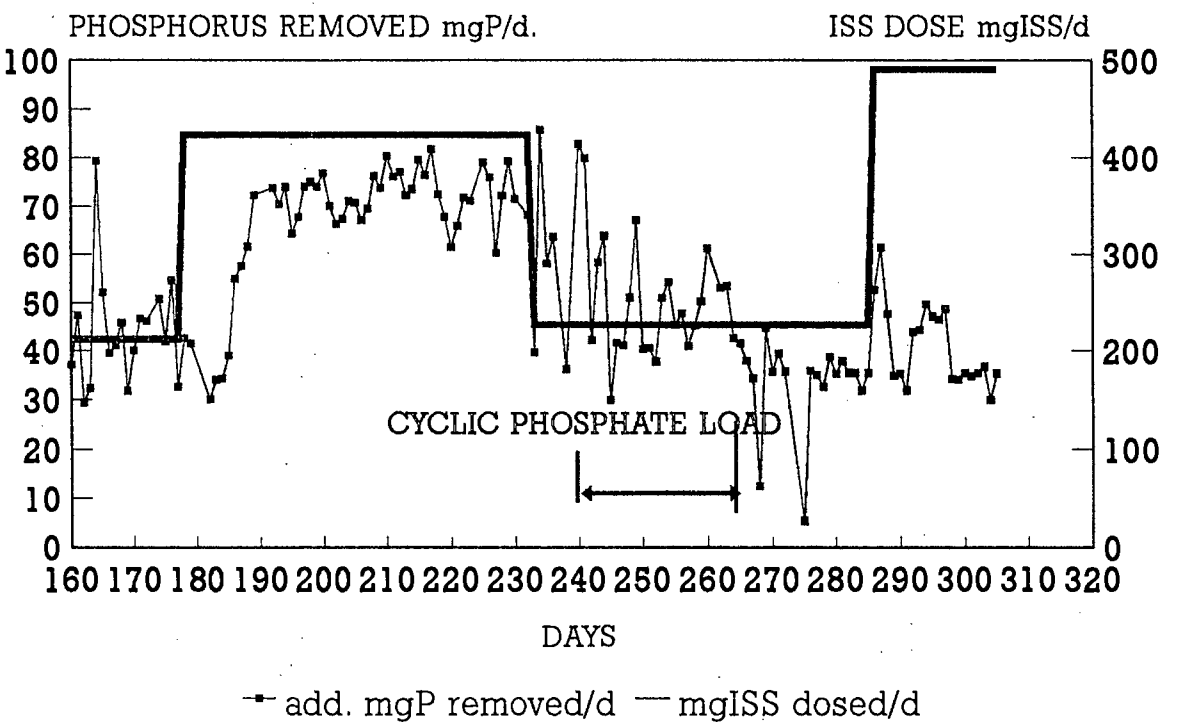


Figure 3.10(b)

The bracketed P removed/ISS added ratios in Table 3.15 were discarded as non steady state values. The remaining data from Table 3.15 were plotted as mgP removed vs mgISS added. A linear regression analysis on the data in Figure 3.11 (constrained to pass through the origin) yielded an average mgP removed/mgISS added of 0.178 with a correlation coefficient of 0.85. Converting the ISS mass to the equivalent Al mass (ie 0.53 mgAl/mgISS, see Section 3.3) gives a P removal of 0.336 for the ratio mass P removed/Al mass added.

Stoichiometrically the precipitation of $AlPO_4$ from $Al(OH)_{3(s)}$ can be represented as follows:

$$Al(OH)_{3(s)} + PO_4^{3-} \text{ ---> } AlPO_4 + 3(OH)^-$$

From this it can be seen that 27 mgAl precipitates 31 mgP giving a stoichoimetric ratio of 31/27 = 1.15 mgP/mgAl. From the removal achieved with the alum sludge (ie 0.34 mgP/mgAl) it can be seen that just under 1/3rd of the stoichiometric ratio was achieved in the Experimental system.

To check the effect of diurnal variations in P load on P removal while maintaining a constant alum dosage rate, a cyclic phosphorus load was placed on both laboratory systems from day 236 to 262 by doubling the influent P supplement and dosing the doubled supplement only every second day, while the daily alum dosing remained unchanged. The influent and effluent P concentrations to and from the Experimental and Control systems are shown in Figure 3.12. It can be seen from Figure 3.12 that the cyclic phosphorus load had very little effect on the phosphorus concentration in the effluent from either system. This is attributable to hydraulic balancing in the systems. It also shows that alum dosing can take place at a constant rate even if the phosphorus load varies. From Table 3.15 period 12; (day 247 to 262) it can be seen that over the period the cyclic phosphorus load was imposed, the stoichiometric ratio, P removed/ISS added was not adversely effected, ie even though the P load varied cyclically while the alum was dosed constantly, the P removed remained the same at about 0.21 mgP/mgISS dosed, which is somewhat higher than the average ratio of 0.178 mgP removed/mgISS alum dosed achieved in the investigation.

MASS OF P REMOVED VS MASS ISS ADDED IN EXPERIMENTAL SYSTEM.

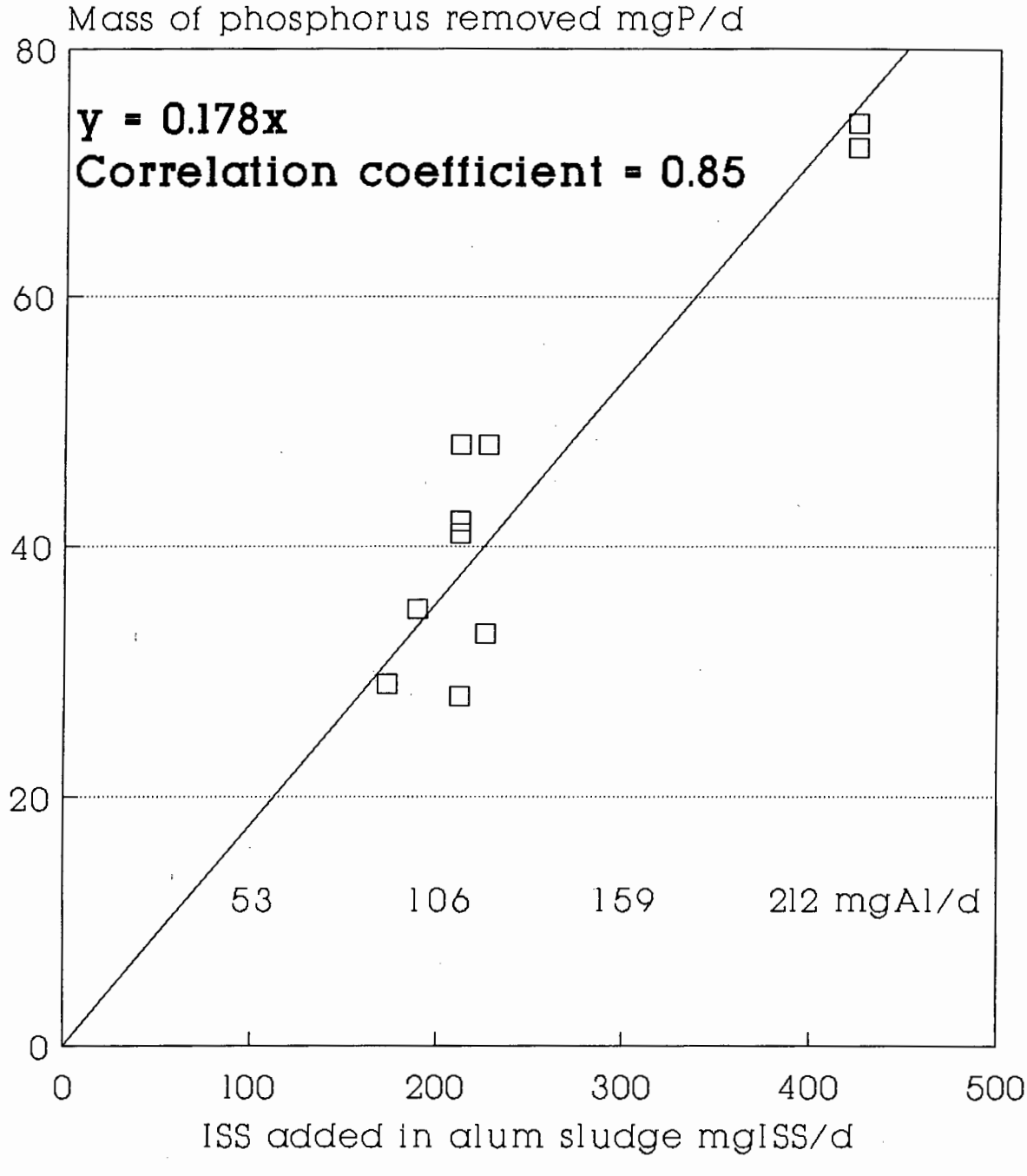


Figure 3.11

PHOSPHORUS CONCENTRATIONS DURING CYCLIC LOAD FOR CONTROL AND EXPERIMENTAL SYSTEM

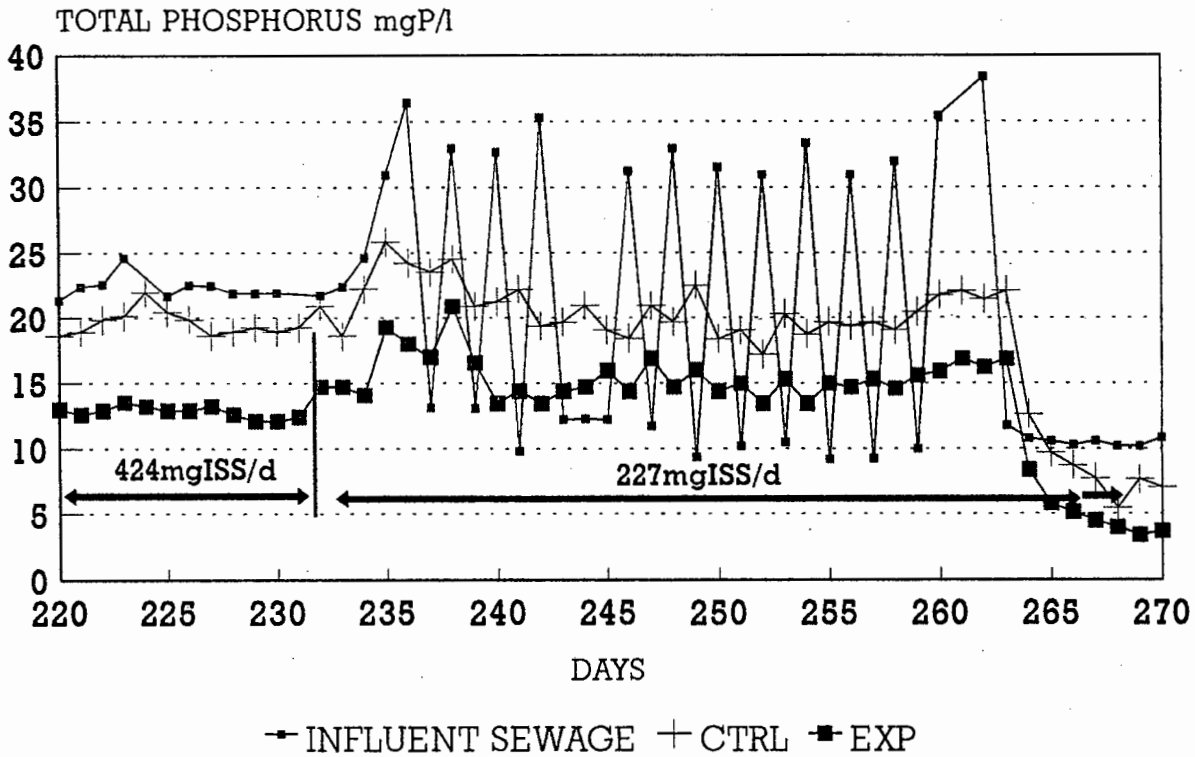


Figure 3.12

On day 262 the mass of influent phosphorus was reduced from 246 to 109 mgP/d by terminating supplementary phosphorus dosing into the influent. This was done to investigate the ability of the alum sludge to achieve low P concentrations. From Fig 3.9(b) it can be seen that from day 262 the influent P reduced to about 10mgP/l, the effluent P concentration from the the Control system to between 6 and 7 mgP/l and that from the Experimental to between 2 and 3 mgP/l. From Table 3.15 (day 275 to 284) it is seen that the P removed/ISS ratio was 0.146, which is slightly lower than the average stoichiometric value obtained of 0.178 (Fig 3.11). It was concluded from this that alum sludge also is effective in precipitating phosphorus at low P concentrations but the removal efficiency decreases as the effluent P concentration decreases, below 5 mgP/l.

3.5.10 Alkalinity and pH

The pH in each of the laboratory systems was measured daily and is plotted in Figs 3.13(a) and (b) and varied between 7.3 and 8.2 with an average value of 7.6 for both units. There was no detectable difference between the pH of the Control and Experimental systems.

In the pH range that the laboratory scale systems were operated phosphorus is present almost entirely as HPO_4^{2-} and $H_2PO_4^-$ (Loewenthal et al, 1989). An increase in alkalinity takes place when phosphorus is precipitated by the aluminium hydroxide in the alum sludge, this increase being due to the release of hydroxide ions in accordance with the following reactions:

$$Al(OH)_{3(s)} + HPO_4^{2-} \rightarrow AlPO_4 + H_2O + 2(OH)^-$$

$$Al(OH)_{3(s)} + H_2PO_4^- \rightarrow AlPO_4 + 2H_2O + (OH)^-$$

An attempt was made to measure the increase in alkalinity due to phosphorus precipitation in the laboratory systems but due to the relatively large changes in alkalinity associated with the nitrification - denitrification reactions no

EFFLUENT pH FROM CONTROL AND EXPERIMENTAL SYSTEM

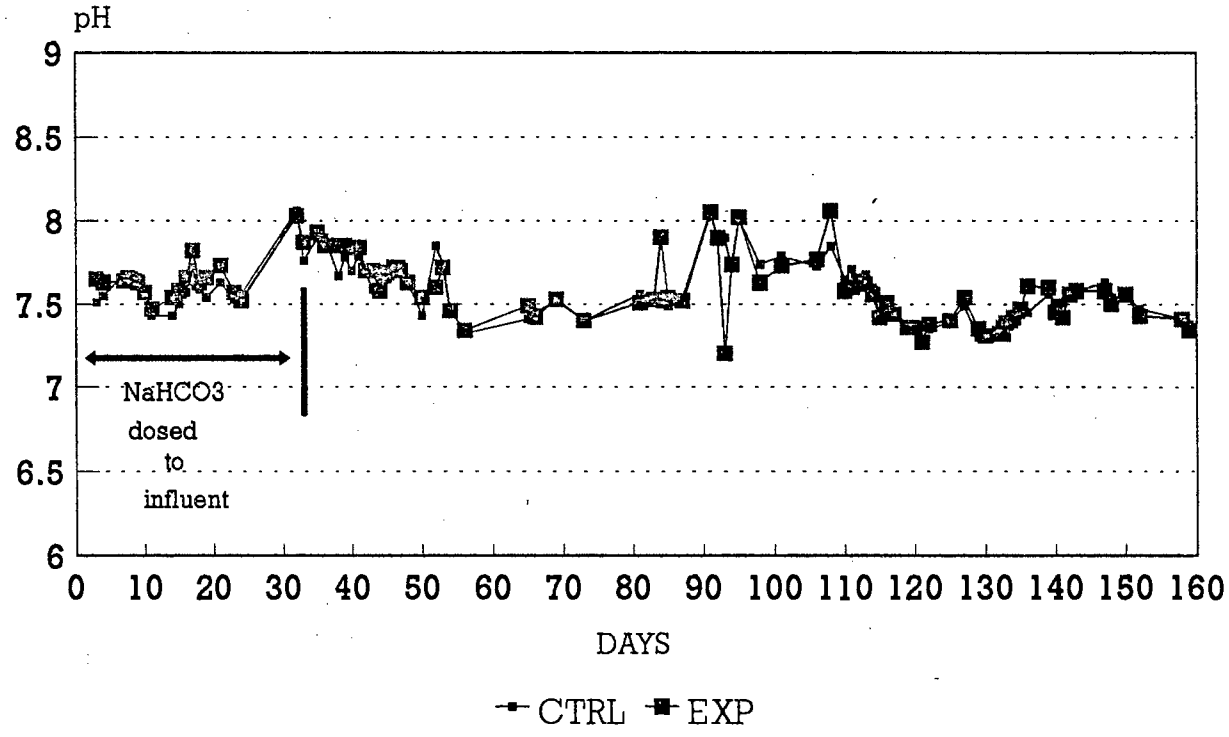


Figure 3.13(a)

EFFLUENT pH FROM CONTROL AND EXPERIMENTAL SYSTEM

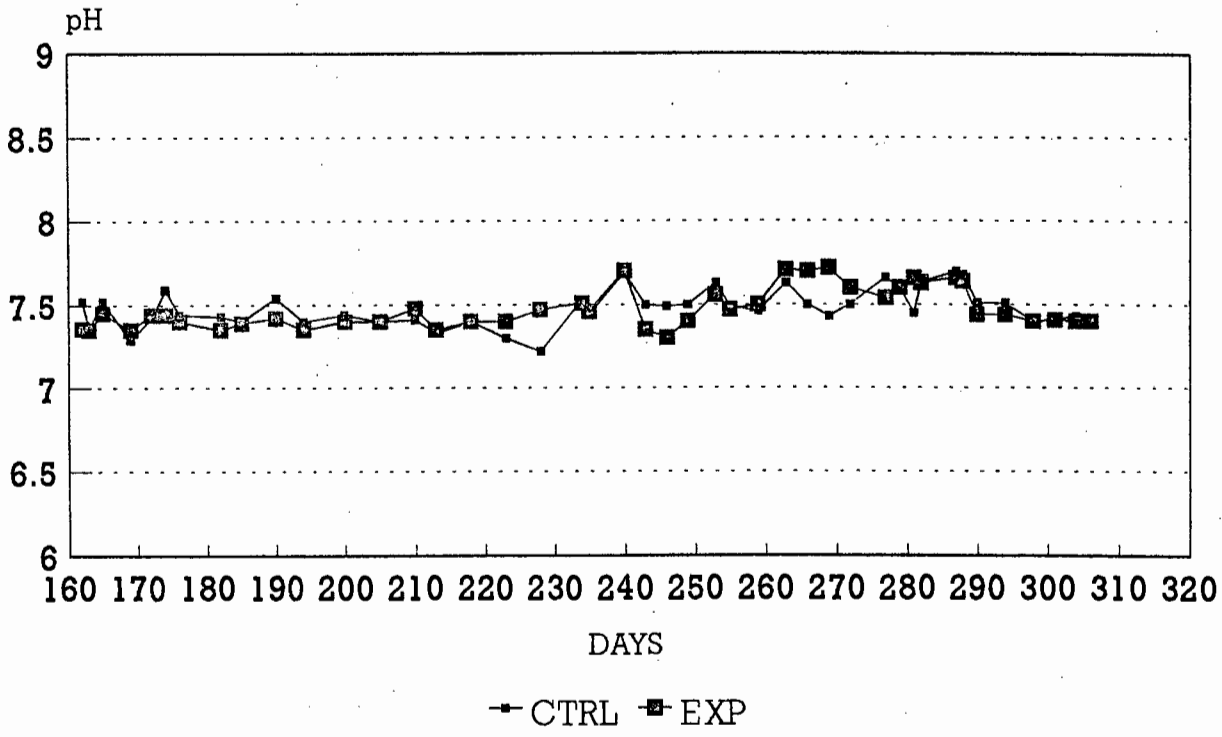


Figure 3.13(b)

meaningful results were obtained and have therefore not been included in this thesis. It was however possible to measure the increase in alkalinity during the stirred jar batch tests by measuring the amount of strong acid required to control the pH (see Section 3.6.4 below).

3.5.11 Dewaterability of sludges

Alum sludges from waterworks treating raw coloured water for potable water supplies are generally difficult to dewater due to the predominance of gelatinous aluminium hydroxide formed in sweep coagulation. Buchner funnel tests to determine the Specific Resistance to Filtration (SRF) as well as tests to determine Capillary Suction Times (CST) were done on the alum sludge collected from Kloof Nek waterworks, one of the sources of sludge used for dosing in this investigation (Izzett, 1989). An average SRF of 70×10^{12} m/kg and CST of 25 seconds were measured for the alum sludge indicating that it is a sludge with poor dewatering characteristics.

Three types of sewage treatment sludge viz activated, primary, and anaerobically digested were collected from the Athlone and Zeekoeivlei wastewater plants in Cape Town to evaluate the effect of alum sludge addition on the dewaterability of sewage sludges. By simply blending alum sludge with the three sewage sludges in various proportions, it was observed that if the sludge to which the alum sludge was added dewatered more poorly than the alum sludge (which was the case for the anaerobically digested sludge), then the dewatering characteristics of the mixture would improve with alum sludge addition in proportion to the relative contribution of the alum sludge. Conversely, if the sewage sludge to which the alum sludge was added dewatered better than the alum sludge (which was the case with the activated sludge), the dewatering characteristics of the mixture deteriorated with alum sludge addition in proportion to the relative contribution of the alum sludge. These results seem reasonable and in conformity with what is expected when blending sludges with different dewatering characteristics. The results of these experiments are given in Appendix D.

In addition to the above tests a series of SRF tests were done on sludges drawn from the two laboratory systems to evaluate the effect of alum sludge dosing on the dewaterability of activated sludge in the Experimental system. These tests were done during steady state periods 12 and 13 when alum sludge accounted for approximately 45% of the Total Suspended Solids (TSS) mass in the Experimental system. Because sludge settleability (DSVI), is known to effect the SRF, increasing as DSVI increases (Smollen, 1986), the DSVI in the Control and Experimental systems were noted when the SRF tests were done and were around 100 ml/g in the Experimental system and between 200 and 210 ml/g in the Control system (Fig 3.16(b). The results of these tests is presented in the form of a histogram in Fig 3.14.

In Fig 3.14 it can be seen that the SRF values for the Experimental system are slightly lower than those for the Control system. This small difference is in all likelyhood attributable to the differences in DSVI, being lower in the Experimental system (100ml/g) than in the Control system (200 to 250 ml/g). However the important result from Fig 3.14 is not that the SRF of the Experimental and Control systems are slightly different, but that the results are so closely the same in comparison with the SRF of the alum sludge. This indicates that the addition of alum sludge to the Experimental system had no adverse effect on the dewaterability of the activated sludge when compared with the Control system ie even though the alum sludge (SRF 60 x 10^{12}m/kg) dewatered much more poorly than the activated sludge (SRF 20 x 10^{12}m/kg), the dewaterabilty of the mixture was now the same if not slightly better than the activated sludge (SRF 15 x 10^{12}m/kg). This is in direct contrast to the earlier results obtained when alum sludge was mixed directly with sewage sludges.

These results show that the addition of alum sludge to the Experimental system has a considerable beneficial effect on the dewaterability of alum sludge itself. This is in all likelyhood due to the transformation of the gelatinous aluminium hydroxide to an aluminium phosphate precipitate, which has very little bound water compared to aluminium hydroxide. This conclusion finds support from the contrary observation that at plants using excess commercial aluminium sulphate as a means to remove phosphorus, deterioration in the dewaterability of the resulting chemically laden biological sludges (Schmidt et al, 1979) has been reported due to the presence of gelatinous aluminium hydroxides.

COMPARISON OF SPECIFIC RESISTANCE VALUES IN LABORATORY SYSTEMS

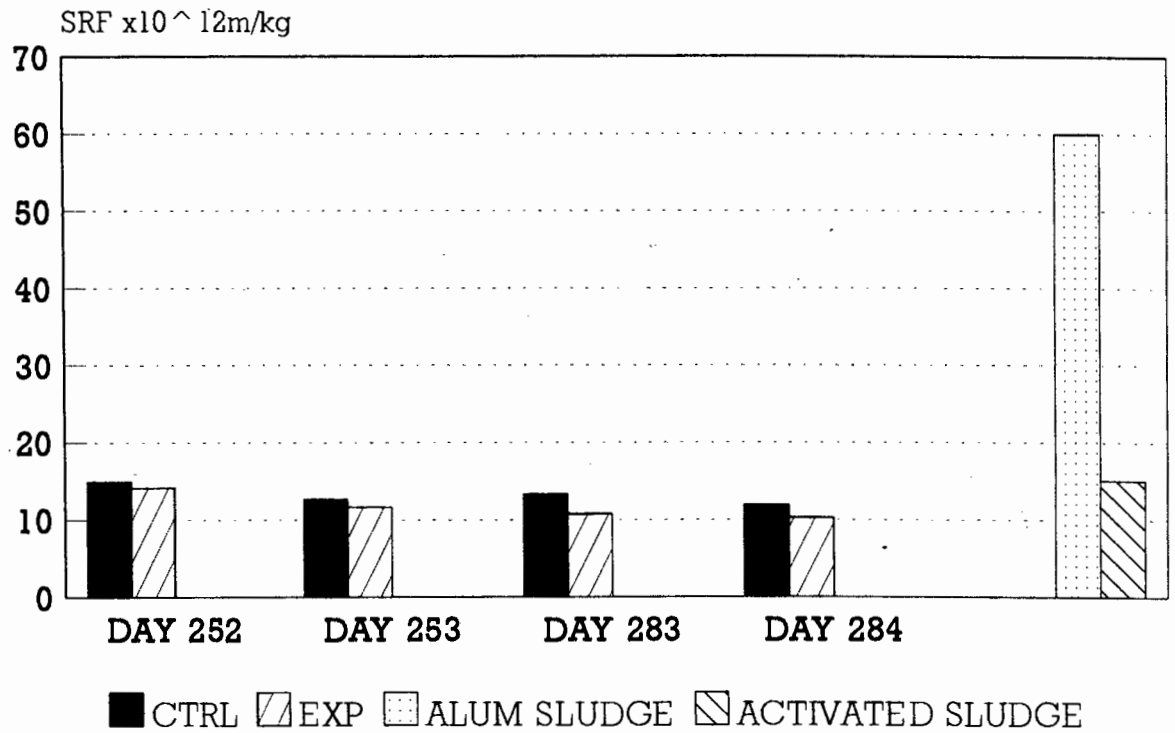


Figure 3.14

3.5.12 Effluent Turbidity

In the exchange of the hydroxide ions with phosphate in the phosphorus precipitation reaction it is possible that a release of fine hydrophilic colloidal matter from the alum sludge to the wastewater stream takes place. This was checked by visually examining and measuring the effluent turbidity of the two systems. Throughout the investigation a brownish colour was observed in the effluent of the Experimental system indicating that some of the humic and fulvic acids of the raw water supply were released into the wastewater and probably accounts for the increased COD of the effluent of the Experimental system (see Section 3.5.2 above). The increase in colour measured in terms of turbidity (NTU) of the effluent from the Experimental system due to the addition of alum sludge over that from the Control system is plotted in Figure 3.15.

3.5.13 Diluted Sludge Volume Index (DSVI)

The MLE systems operated in this investigation were selected not only because they allow COD and N balances to be conducted but also to observe the filamentous bulking behaviour of the MLE nitrification-denitrification (ND) system. Up to this investigation, virtually only single reactor intermittent aeration ND systems had been operated in the bulking research programme and it became necessary to observe the bulking behaviour of MLE type systems. The MLE systems, while also ND systems, are very different to intermittent aeration (IA) systems: In the MLE anoxic and aerobic conditions are established in separate reactors with inter-reactor flows set up by underflow and mixed liquor recycles; in the latter, anoxic and aerobic conditions are created by intermittent aeration within the same single reactor. Both systems are continuously fed but in the MLE all the influent is discharged into the anoxic reactor whereas in the IA influent is discharged to both anoxic and aerobic conditions. The MLE system does not have marked periods of low DO concentrations whereas in the IA system periods of low DO occur each time the system switches from aerobic to anoxic conditions. In the MLE system the frequency with which the sludge is exposed

FILTERED EFFLUENT TURBIDITY FROM CONTROL AND EXPERIMENTAL SYSTEMS

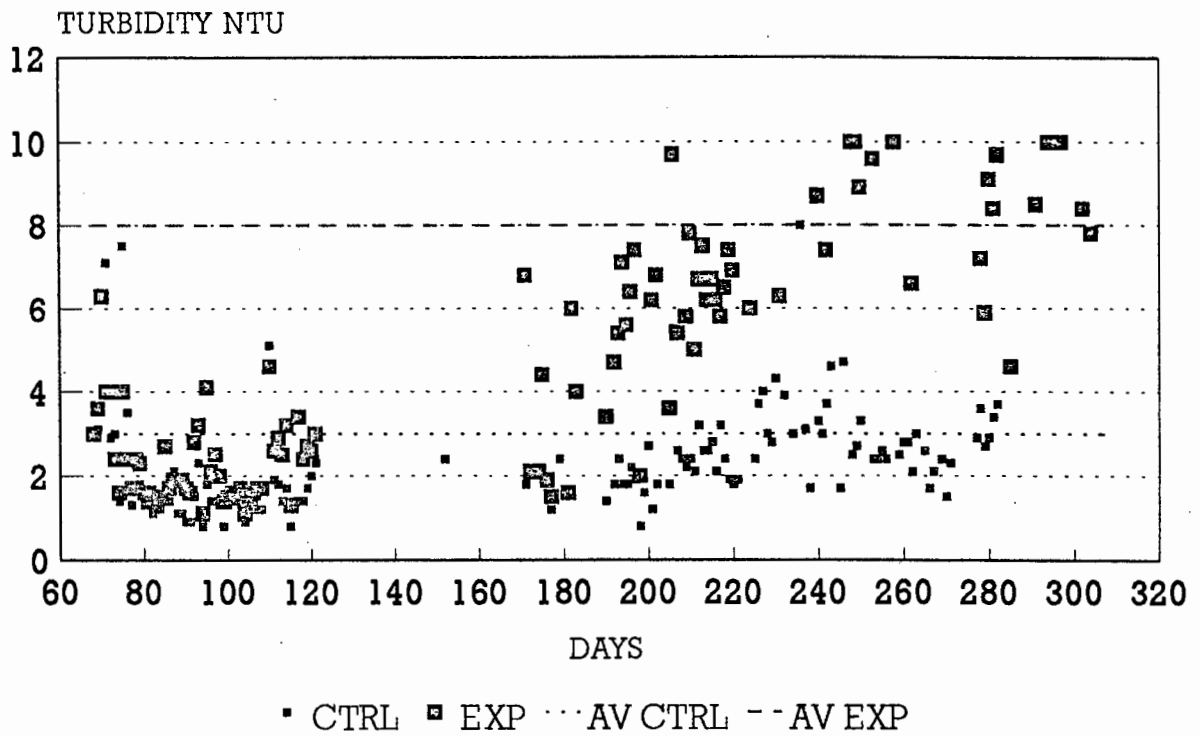


Figure 3.15

to alternating anoxic and aerobic conditions is controlled by the inter-reactor recycle flow rates or ratios and varies from about 2 times per day at a zero mixed liquor a-recycle to 6 times a day at a 4:1 mixed liquor a-recycle. In the intermittent aeration system the frequency with which the sludge is exposed to anoxic and aerobic conditions is controlled by the aeration cycle time which typically varies from 10 minutes to 30 minutes which yields frequencies of anoxic-aeration alternation of 144 to 48 times per day, much higher than in the MLE system. Clearly, the MLE and IA systems establish markedly different ND conditions and the effect of these differences were of considerable interest in the bulking research programme. So to create low F/M filament bulking coditions in the MLE systems a large anoxic sludge mass fraction (70%) was chosen for them because it had been observed earlier in single reactor intermittent aeration systems that large anoxic mass fraction promote low F/M filament proliferation and bulking, mainly Microthrix parvicella, but also 0092, 0041, 1851 and 0675. (Gabb et al, 1989; Warburton et al 1991).
The settleability of the sludge in terms of the Diluted Sludge Volume Index (DSVI) measured in the Experimental and Control systems during the investigation, as well as results of the filamentous organism identification tests conducted every 3 to 4 weeks are given in Fig 3.16(a) and (b). Details of the filament identification are given in Table 3.16.

In starting up, the Experimental and Control systems were seeded with sludge from nutrient removal MUCT systems that were operated in the UCT laboratory. These MUCT systems exhibited low F/M filament bulking conditions (high DSVI'S) with filaments 0092 and M. parvicella dominant (Table 3.16). Consequently the Experimental and Control systems initially also exhibited high DSVI'S with similiar dominant filaments (Fig 3.16 (a)).

DSVI
FOR CONTROL AND EXPERIMENTAL SYSTEMS

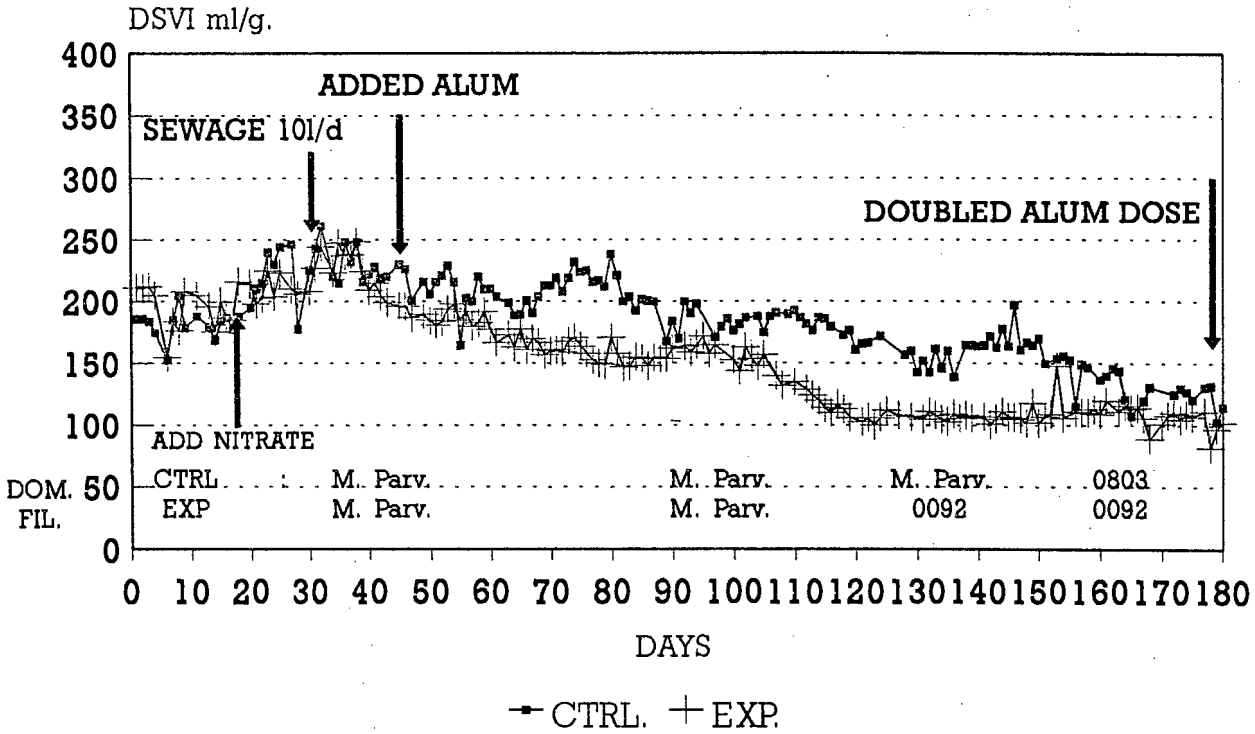


Figure 3.16(a)

DSVI
FOR CONTROL AND EXPERIMENTAL SYSTEMS

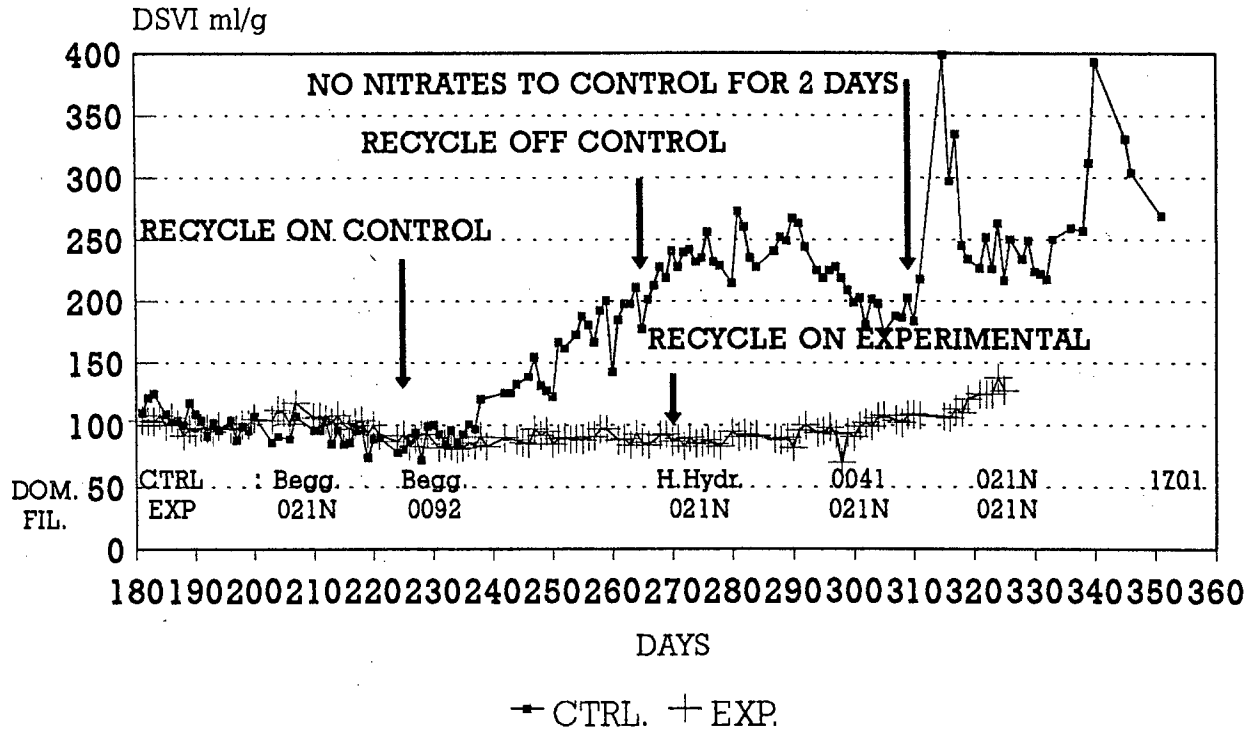


Figure 3.16(b)

Table 3.16 Continued: Filamentous organism identification

Date 1989	Day No.	Sys.	DSVI ml/g	Filament identification.			
				Dominant	Secondary	Other	Rel. Abund.
03 Aug	192	Ctrl	91	Beggiatoa	H. hydr.	021N; 0041.	very common
03 Aug	192	Exp	97	021N	H. hydr.	0092; 0041; Beggiatoa Flexi-bacter.	common
11 Sep	231	Ctrl	93	Beggiatoa	0041	H. hydr.; 0092; 1851; 021N.	very common
11 Sep	231	Exp	82	0092	0041	1851; 021N.	common
25 Oct	275	Ctrl	235	H. hydr.	021N	0041; 0092.	common -very common
25 Oct	275	Exp	86	021N	0041	0092; H. hydr.	common
20 Nov	301	Ctrl	203	0041	0092	H. hydr.; 021N.	very common
20 Nov	301	Exp	99	021N	0041	H. hydr.; 0092.	little
14 Dec	325	Ctrl	217	021N	0092	M. parv.; 0041	very common
14 Dec	325	Exp	128	021N	H. hydr.	0041; 0092	little
17 Jan 1990	359	Ctrl	269	1701	0092	H. hydr.; 0041; 021N.	very common -abund

On day 18, nitrate was dosed to the anoxic reactors of both systems thereby causing a termination of biological excess P removal. The sludges of the Experimental and Control systems continued to settle poorly reflected by an increasing DSVI to about 250ml/g on day 30, and causing solids loss due to settling tank overload. On day 30 the influent flow and COD load were reduced by a third by reducing the influent flow from 15 to 10 l/d and reactor MLSS mass was reduced proportionally in conformity with the reduced COD load. The lower influent flow and reactor MLSS brought relief to the settling tanks and solids loss with the effluent no longer took place. The filamentous organisms in the systems during this period of poor settleability were M. parvicella, 0803, 0092, 1851, and 0041 (see Table 3.16, day 42). Except for 0803, these filaments are common low F/M filaments encountered in intermittent aeration ND and NDBEPR MUCT systems.

From the period of poor settleability around day 30 to 35, slowly but steadily, the DSVI in both systems declined until by day 220 it was around 100 ml/g in both systems. During this time M. parvicella progressively declined in the systems (Table 3.16) and its disappearance probably accounts for the improvement in settleability. From this it was concluded that the different ND conditions in the MLE systems compared to intermittent aeration (IA) systems significantly influence the filamentous organisms in the sludge leading to different settling behaviour. Whilst filaments 0092, 0041, 1851 grow in both MLE and IA systems, the absence of M. parvicella in the former seems to lead to good sludge settleability in the MLE (DSVI approx. 100 ml/g) whereas the presence of M. parvicella in the intermittent aeration systems causes poor settleability (DSVI > 200 ml/g) in these systems.

Although as outlined above there are many differences between the MLE and IA systems, it was thought that the main difference between the MLE and IA systems was that in the former the frequency of alternation between anoxic and aerobic conditions was once daily whereas in the IA system between 48 and 144 times daily. To increase the frequency of alternation, on day 226 an a-recycle at a ratio of 3,7:1 was installed in the Control system.

On day 235, the DSVI in the Control system began to increase and by day 265 it was around 200 ml/g. (Fig 3.16(b)). The dominant and secondary filament in the sludge on day 275 when the DSVI was 235 ml/g was H. hydrossis and 021N respectively. Curiously H. hydrossis is seldom observed in full scale ND and NDBEPR systems and 021N appears in the sludge of laboratory systems when the storage vessels in the cold room are not regularly and thoroughly cleaned. Because the filaments causing the increased DSVI are not the usual ones causing poor settleability in the laboratory ND systems, it is difficult to attribute the higher DSVI in the Control system directly to the increased recycle ratio. Interestingly, the DSVI in the Experimental system remained low at 100 ml/g with the main filaments being 021N and 0041. (Table 3.16).

To see if the effect of the a-recycle on the DSVI could be reversed on day 265 the 3.7:1 a-recycle was taken off the Control system and a 4:1 a-recycle incorporated in the Experimental system. In the Control system without the a-recycle the DSVI began to decline. Twenty days later (day 310) the DSVI had declined to about 180 ml/g. During this time the filament H. hydrossis declined and 021N became the dominant filament. In the Experimental system the DSVI remained low at around 100 ml/g with the dominant filaments 021N and 0041. However in the Experimental system with the a-recycle, the DSVI did eventually begin to increase from day 300 and by day 325 the DSVI was 130 ml/g. Interestingly also, H. hydrossis increased in importance during this period. It would appear from this that increases in frequency of alternation promote the profileration of H. hydrossis. This was also observed in intermittent aeration systems fed real and synthetic sewages (Casey et al, 1990, 1991). On day 325 the operation of the Experimental system was terminated.

The downward trend in the DSVI of the Control system after the a-recycle was removed, suddenly stopped on day 312. On this day the pump which dosed the nitrate to the anoxic reactor reactor broke down causing a zero nitrate feed to the anoxic reactor for a period of 12 hours. This had a dramatic effect on the DSVI causing it to increase precipitously to 400 ml/g and then decline again to around 230 ml/g over a 7 day period after the pump breakdown. On day 325 the dominant filaments were 021N and 0092 and interestingly, M. parvicella, which had not been identified since the beginning of the investigation, reappeared.

However, the appearance of M. parvicella is probably a laboratory artefact due to the failure to properly clean the DO probe used in another laboratory system, because between days 330 and 350, the last 20 days that the Control system was operated, another increase and decrease in DSVI took place. It is not clear what caused this behaviour and curiously, by the end of this period, 021N had declined from the system and a new filament 1701 which is not a low F/M filament had risen to predominance.

It is difficult to interpret the bulking behaviour of the Control system over the last 40 days of the investigation but the behaviour of the two systems indicates that:

(1) low F/M filaments did not proliferate in 2 reactor ND systems and maintained a low DSVI of around 100 ml/g. The absence of M. parvicella a filament dominant in intermittent aeration ND systems was notable. The filaments present in the systems were 0092, 0041, 0803, and 021N, the last named probably as a result of a laboratory system artefact through storage of sewage which increases the risk of feeding septic sewage;

(2) increasing the frequency of alternation between anoxic and aerobic conditions appears to encourage the proliferation of H. hydrossis.

3.6 STIRRED JAR BATCH TESTS

A series of stirred jar batch P precipitation tests were done (Airey, 1989) with alum sludge and commercial (unused) aluminium sulphate as precipitants at various controlled pH values so that the P removal ability of the alum sludge observed in the presence of activated sludge in the Experimental system could be compared
with :

(i) the P removal in the absence of activated sludge;
(ii) the P removal by commercial (unused) aluminium sulphate.

The stirred jars were prepared by placing exactly 500ml of solution with a known orthophosphate concentration in glass beakers and the pH adjusted to the required value by the addition of a strong acid or base. A measured volume of alum sludge of known ISS concentration, or aluminium sulphate of known Al concentration, was added to each of the beakers. Thereafter the beakers were continually gently stirred, covered with aluminium foil and run for 20 to 25 days.

Over the 20 to 25 day period samples were withdrawn from the beakers for P determination. The pH of the solutions was monitored daily and adjusted to the prescribed pH value using Hydrochloric acid prior to withdrawing samples. The samples were immediatley filtered through Whatman number 42 filter paper and the filtrate was analysed to determine the phosphorus concentration. The mass of phosphorus removed was calculated taking into account the dilution effect due to the volume of alum sludge added. The volume of strong acid added for pH adjustment was small enough to be ignored.

3.6.1 Phosphorus removal using alum ISS in stirred jar batch tests

Altogether 17 jar tests were done with alum sludge and the initial phosphorus mass, alum mass ISS dosed, and phosphorus mass removed after 1, 2, 5, 10, 15 and 20 days are listed in Table 3.17. Details of the experimental results are given in Appendix E.

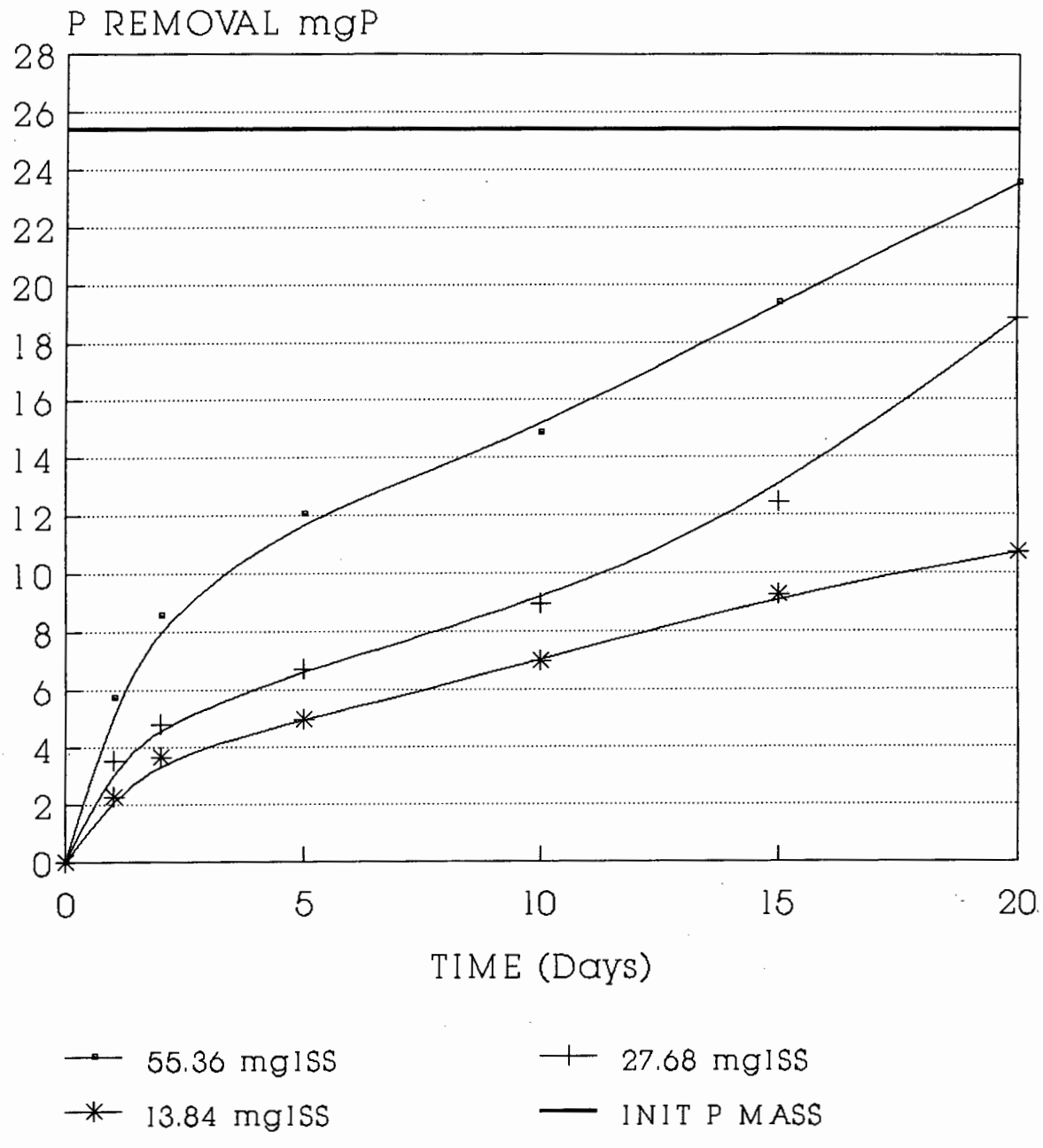
From the data in Table 3.17, the mass of P removed was plotted versus reaction time for the selected batch test pH values of 6.8, 7.0, 7.5, and 7.8 in Figs 3.17(a) to (f) respectively. Also shown in the figures is the initial P mass ie the P mass available for the precipitation (solid horizontal line). It should be noted that the results in Table 3.17 and Figs 3.17(a) to (f) are given in masses; because all the batch tests were done at 0.50 l volume, concentrations are simply obtained by multiplying by 2.0.

Examining Figures 3.17(a) to (f) it can be seen that generally in most of the tests the P removal-time plot is curved upwards, but flattening-out as time proceeds, indicating that the P removal per unit time diminishes as time elapses. In some tests, most of the initial P mass was precipitated and in these tests the low residual concentration of P remaining may have limited the P removal.

Table 3.17: **Initial phosphorus mass, alum ISS added, and phosphorus removed after 1, 2, 5, 10, 15, and 20 days in stirred jar batch tests using alum sludge as a precipitant.**

pH & No.	Init. P mass mgP	Mass ISS added mgISS	Mass of phosphorus removed after					
			1 day mgP	2 days mgP	5 days mgP	10 days mgP	15 days mgP	20 days mgP
6.8								
1	25.84	55.36	5.71	8.53	12.04	14.84	19.36	23.52
2	25.38	27.68	3.53	4.80	6.70	8.95	12.44	18.85
3	25.38	13.84	2.29	3.66	4.95	6.94	9.24	10.70
7.0								
4	24.12	55.36	4.89	6.90	6.60	8.92	9.92	10.41
5	24.27	34.60	3.23	4.28	4.56	5.39	6.66	7.11
6	24.27	20.76	1.79	2.85	3.86	5.45	8.25	11.68
7	11.24	55.36	5.26	6.78	8.64	10.30	10.59	10.89
8	11.54	34.60	3.38	3.95	6.50	9.25	10.75	11.20
9	11.54	20.76	2.46	3.34	4.74	7.36	9.68	10.35
7.3								
10	24.93	55.36	5.61	6.16	7.82	11.30	15.47	21.13
11	25.24	27.68	2.62	3.09	4.40	6.44	9.42	15.69
12	25.54	13.84	1.68	2.59	2.68	4.16	5.48	6.96
7.5								
13	24.12	55.36	5.22	6.42	8.55	11.59	15.14	17.60
14	23.08	34.60	3.30	4.64	6.84	9.68	13.25	15.18
7.8								
15	26.29	55.36	5.36	7.03	6.73	8.07	11.01	12.06
16	25.69	27.68	2.45	3.70	4.23	4.99	8.59	9.77
17	25.54	13.84	1.99	2.74	2.38	3.23	5.48	7.27

MASS OF P REMOVED VS REACTION TIME AT A pH OF 6.8

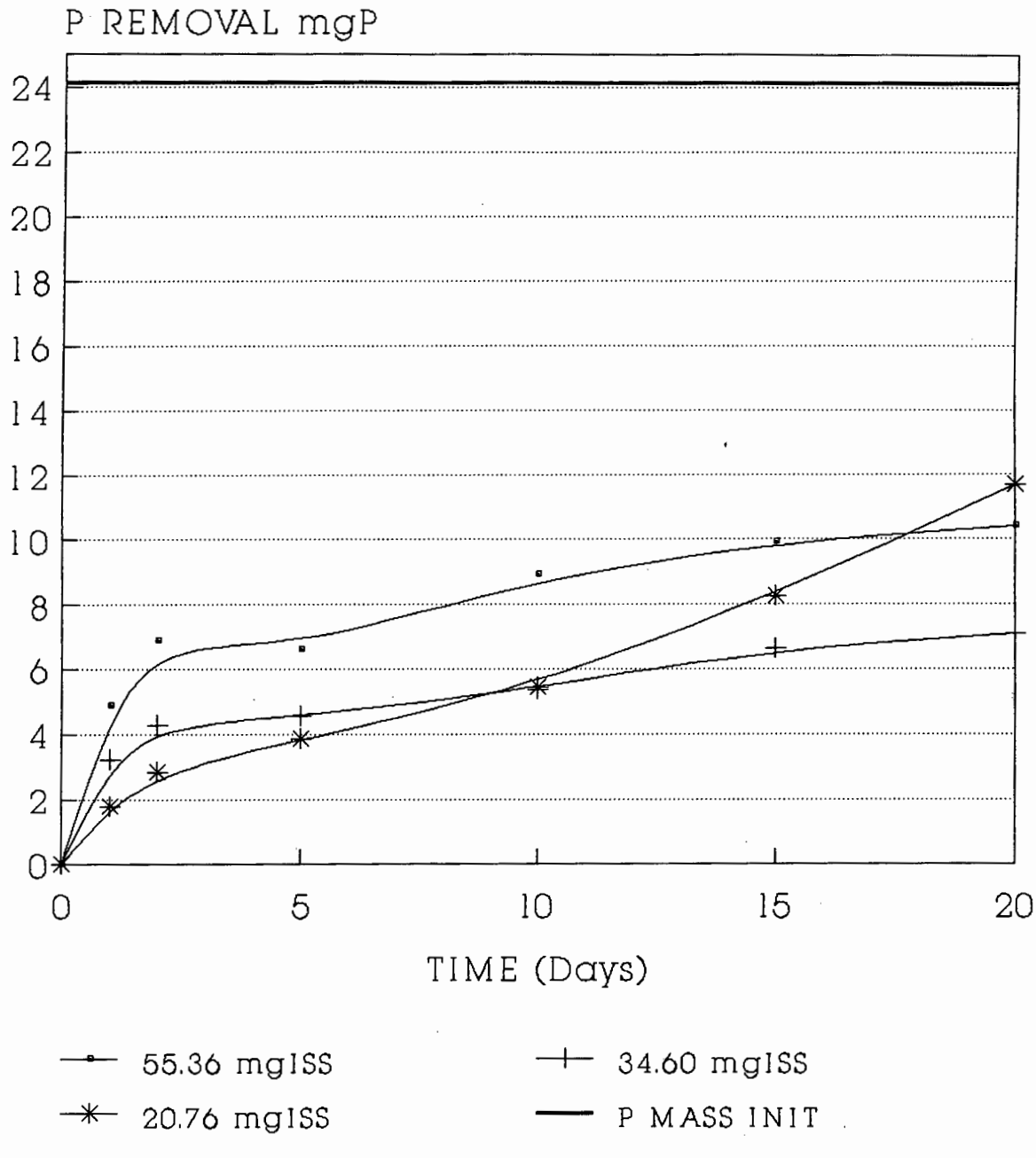


ISS MASS DOSED

BATCH VOLUME = 0.500 litres

Figure 3.17(a)

MASS OF P REMOVED VS REACTION TIME AT A pH OF 7.0

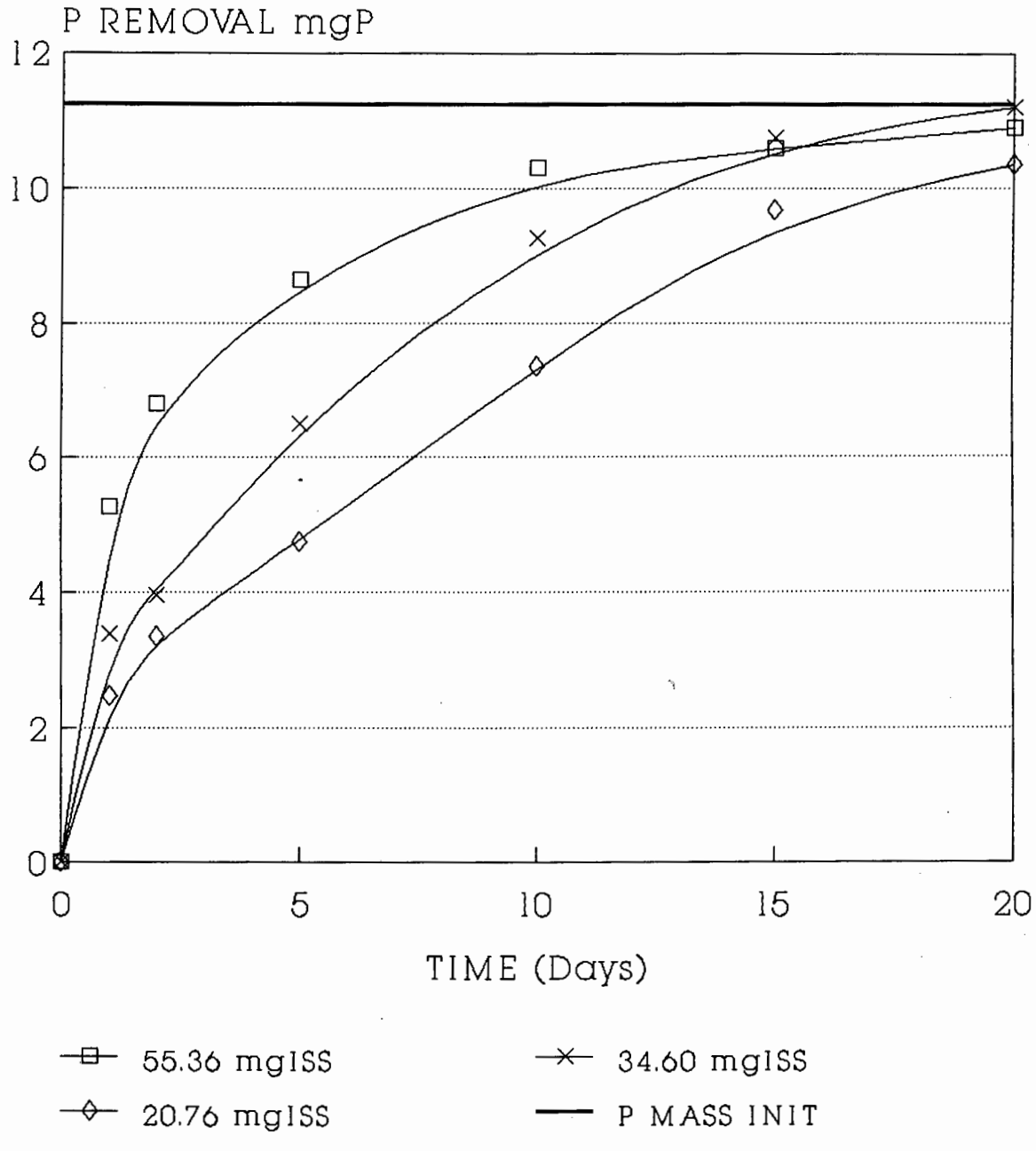


ISS MASS DOSED

BATCH VOLUME = 0.500 litres

Figure 3.17(b)

MASS OF P REMOVED VS REACTION TIME AT A pH OF 7.0

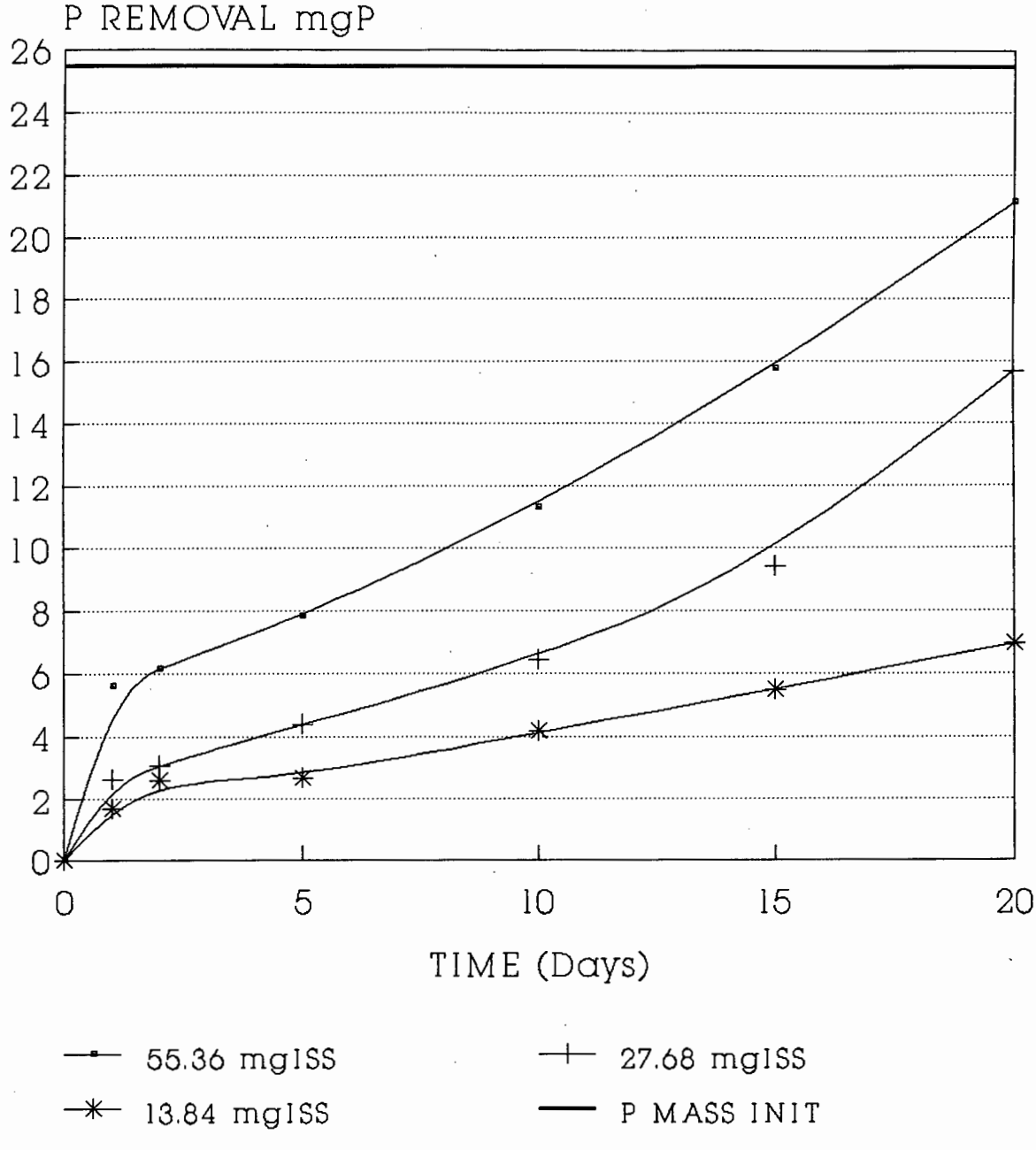


ISS MASS DOSED

BATCH VOLUME = 0.500 litres

Figure 3.17(c)

MASS OF P REMOVED VS REACTION TIME AT A pH OF 7.3

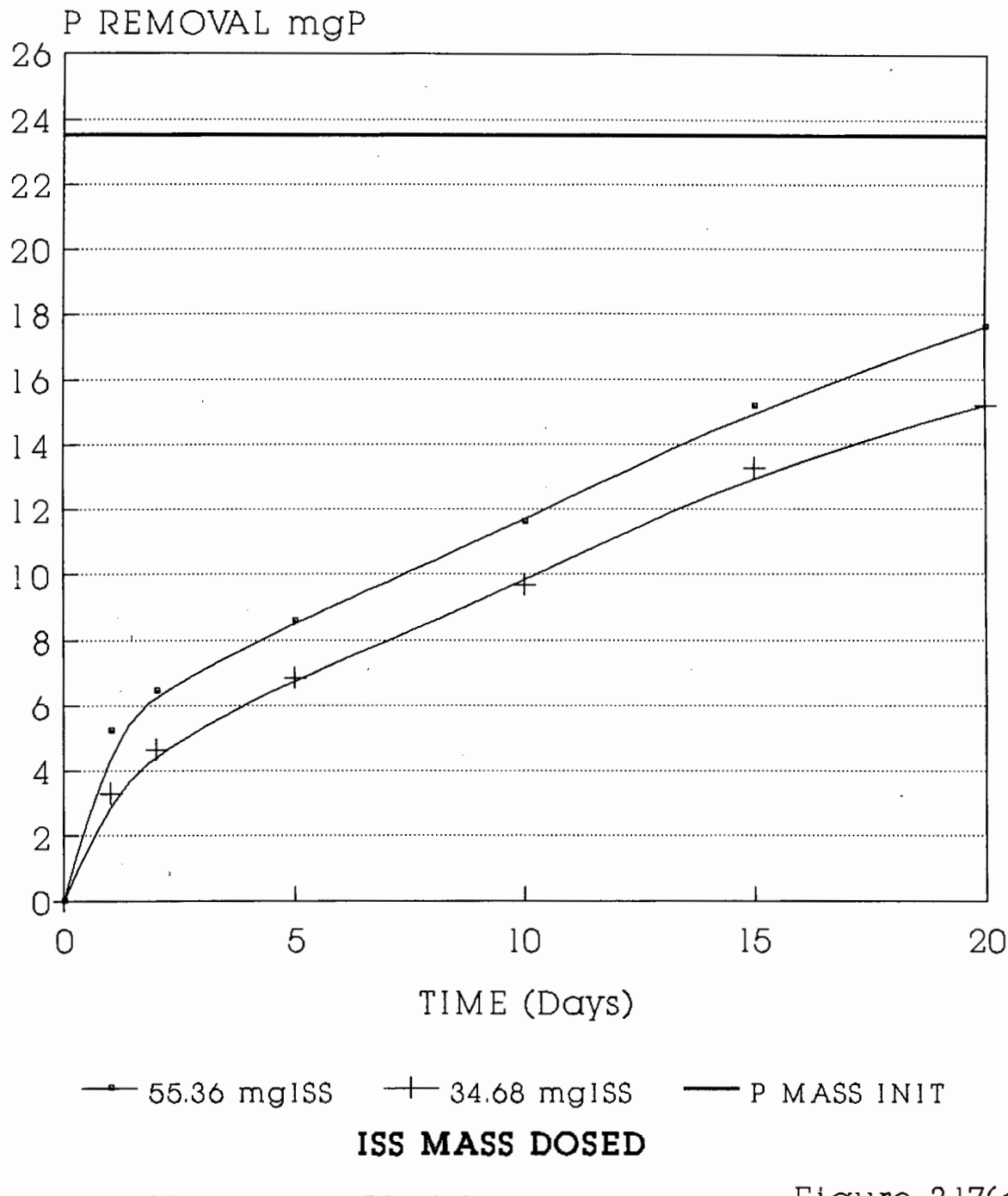


ISS MASS DOSED

BATCH VOLUME = 0.500 litres

Figure 3.17(d)

MASS OF P REMOVED VS REACTION TIME AT A pH OF 7.5

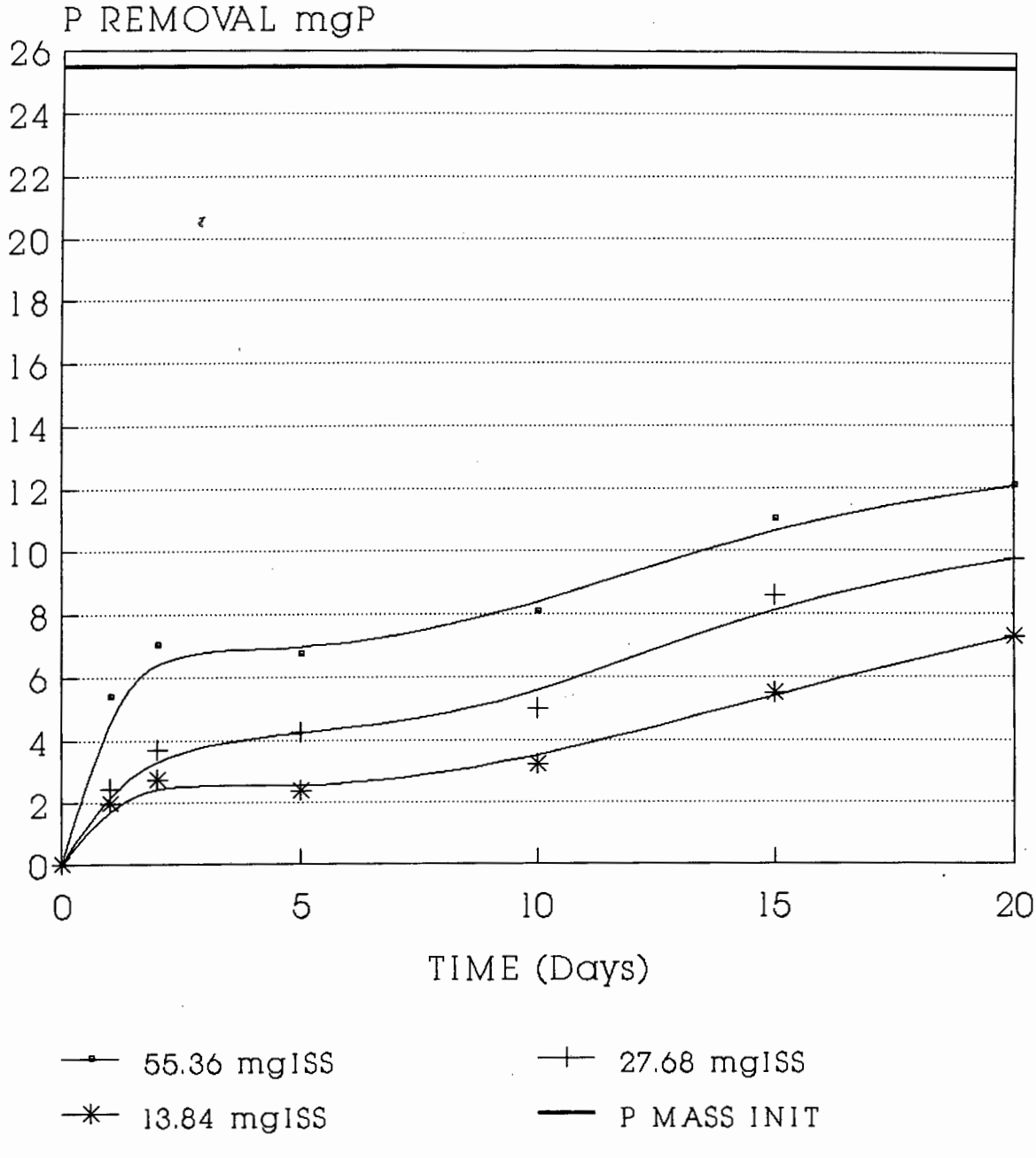


ISS MASS DOSED

BATCH VOLUME = 0.500 litres

Figure 3.17(e)

MASS OF P REMOVED VS REACTION TIME AT A pH OF 7.8



ISS MASS DOSED

BATCH VOLUME = 0.500 litres

Figure 3.17(f)

In order to establish whether or not P limitation effects influenced the batch test results, the percentage stoichiometric removal at 1, 2, 5, 10, 15 and 20 days was calculated and tabulated in Table 3.18 together with the residual P concentration for the 17 batch tests.

Percentage stoichiometric removal (%SR) was calculated as follows;

%SR = ((mgP removed at time t/mgISS dosed)/(0.61mgP/mgISS)) x 100

where 0,61 (mgP/mgISS) = estimated stoichiometric removal for alum sludge

The estimated stoichiometric P removal ratio for the alum sludge was obtained from the P to Al stoichiometric ratio of 31/27 mgP/mgAl (see Section 3.5.9) and the assumption that for the alum sludge the ash remaining after incineration, ie ISS, is all Al_2O_3 which yields the estimated stoichiometric removal ratio for alum sludge of 0.61 mgP/mgISS.

The percentage stoichiometric removal and residual P concentration data listed in Table 3.18 for the 17 different batch tests at the selected pH values of 6.8, 7.0, 7.3, 7.5 and 7.8 are shown plotted as residual P concentrations versus percentage stoichiometric removal in Figs 3.18(a) to (e) for different initial P mass per ISS mass dosed. Examining Figs 3.18(a) to (e) it can be seen that all batch tests yield straight lines for the residual P concentrations versus % stoichiometric removal, even at low residual P concentrations ie P concentrations < 5 mgP/l. From the linearity of the results it was concluded that residual P concentration was not a limiting factor to the P removal observed in the batch tests.

A second important trend can be observed in Figs 3.18(a) to (e) viz the initial P mass to ISS mass dosed ratio plays a part in the precipitation reaction in that the precentage stoichiometric removal increases as the initial P mass to ISS mass dosed ratio increases. However within this general trend three anomalies are observed, these being at the dosing ratios 0.436 and 0.701 mgP initial/mgISS dosed at a pH of 7.0 in Figure 3.17(b) and for the dosing ratio 1.845 mgP initial/mgISS dosed at a pH of 7.3 in Figure 3.17(c). As established earlier these anomalies are not due to P limitation effects, indeed in these instances the lowest P concentation was greater than 25mgP/l. No explanation for these anomolies can be advanced and they have been regarded as outliers in further evaluation of the results.

Table 3.18: **Initial Phosporus mass, alum ISS dosed, dosing ratio (mgP_{init}/mgISS dosed), residual P concentration, and stoichiometric removal, after 1,2,5,10,15, & 20 days, using alum sludge as precipitant.**

pH & Test No.	Init. conc. mgP/l	Mass ISS dosed mgISS	Residual P concentration (mgP/l) & stoichiometric removal (%) after						Dosing ratio P init./ ISS dosed mgP/mgISS
			1	2	5	10	15	20	
			days.						
6.8									
1	48.75	55.36	37.89 17%	32.65 25%	26.03 36%	20.76 44%	12.22 58%	4.37 70%	0.467
2	49.77	27.68	42.84 21%	40.35 29%	36.62 40%	32.22 53%	25.38 74%	12.80 112%	0.917
3	50.77	13.84	46.18 27%	43.43 44%	40.86 59%	36.87 83%	32.28 110%	29.35 127%	1.834
7.0									
4*	45.51	55.36	36.28 15%	32.49 21%	33.05 20%	28.68 27%	26.79 29%	25.87 31%	0.436
5*	47.12	34.60	40.85 15%	38.80 20%	38.26 22%	36.66 26%	34.18 32%	33.31 34%	0.701
6	48.05	20.76	44.51 14%	42.41 23%	40.40 31%	37.26 43%	31.72 65%	24.79 92%	1.169
7	21.21	55.36	11.28 16%	8.42 20%	4.90 26%	1.77 31%	1.23 31%	0.66 32%	0.203
8	22.41	34.60	15.85 16%	14.74 19%	9.79 31%	4.44 44%	1.54 51%	0.66 53%	0.334
9	22.86	20.76	17.99 19%	16.24 27%	13.47 38%	8.28 58%	3.69 77%	2.37 82%	0.556
7.3									
10	47.04	55.36	36.46 17%	35.42 18%	32.28 23%	25.72 34%	17.86 46%	7.18 63%	0.450
11	49.49	27.68	44.36 16%	43.43 18%	40.86 26%	36.87 38%	31.02 56%	18.73 93%	0.912
12*	51.07	13.84	47.70 20%	45.89 31%	45.70 32%	42.76 49%	40.11 65%	37.15 83%	1.845
7.5									
13	45.51	55.36	35.67 16%	33.39 19%	29.38 25%	23.65 34%	16.94 45%	12.31 52%	0.436
14	44.81	34.60	38.41 16%	35.80 22%	31.52 33%	26.02 46%	19.09 63%	15.34 72%	0.667
7.8									
15	49.61	55.36	39.49 16%	36.35 21%	36.92 20%	34.39 24%	28.83 33%	26.85 36%	0.475
16	50.37	27.68	45.57 15%	43.12 22%	42.07 25%	40.59 30%	33.53 51%	31.22 58%	0.928
17	51.07	13.84	47.09 24%	45.59 33%	44.94 36%	44.62 38%	40.11 65%	36.35 86%	1.845

* The data from these tests have been regarded as outliers but have still been plotted in the graphs.

RESIDUAL P CONCENTRATION VS STOICHIOMETRIC REMOVAL AT A pH OF 6.8

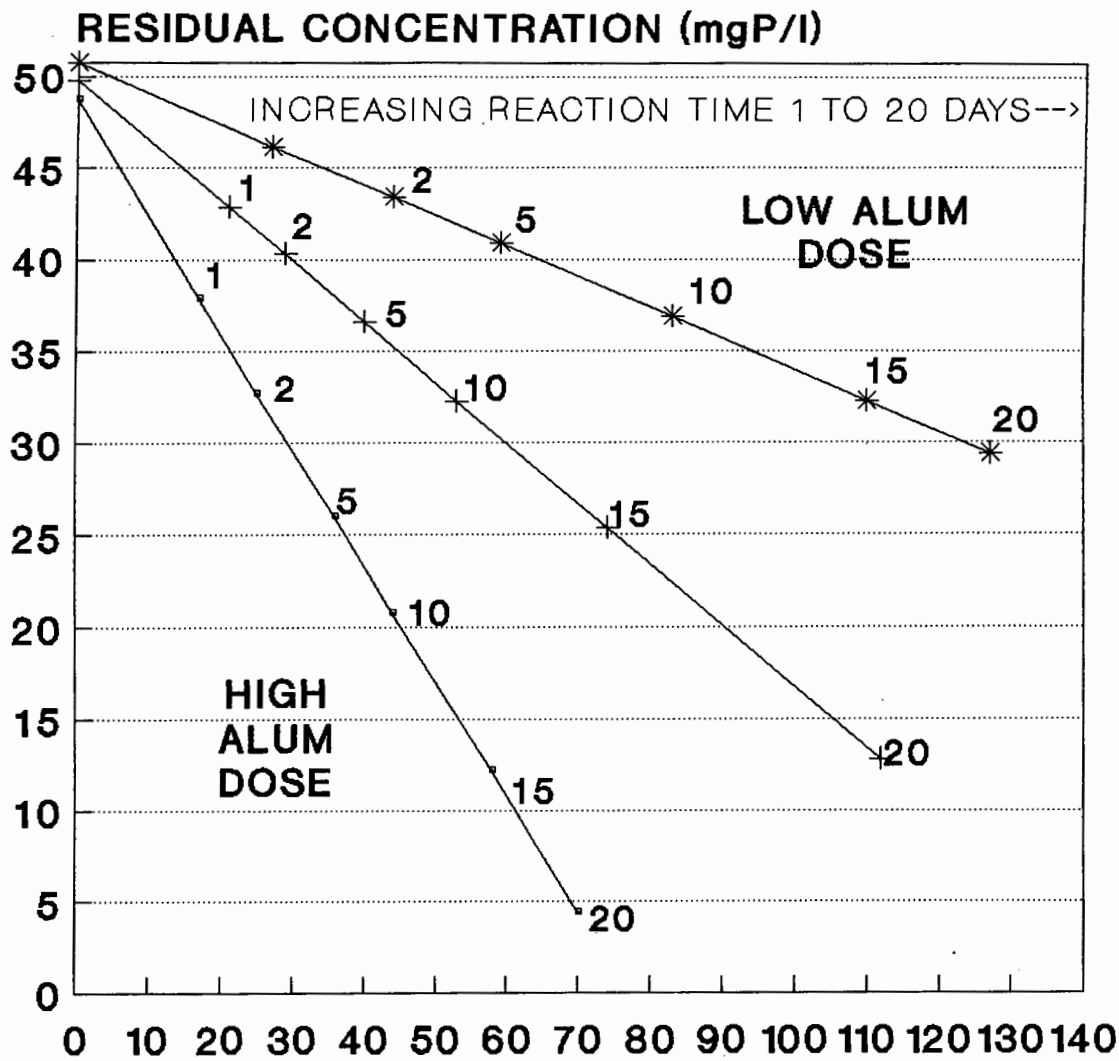


Figure 3.18(a)

RESIDUAL P CONCENTRATION VS STOICHIOMETRIC REMOVAL AT A pH OF 7.0

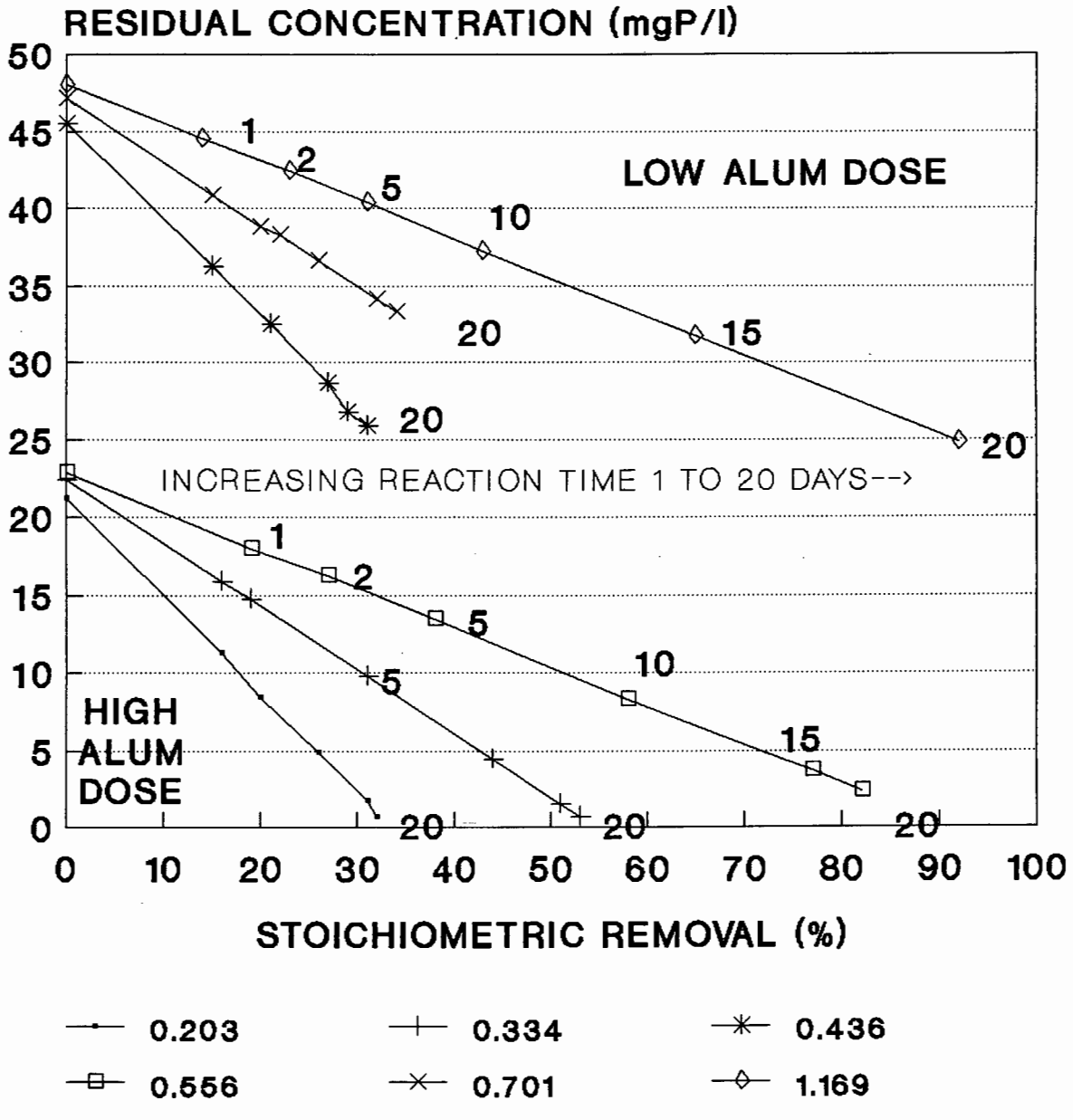


Figure 3.18(b)

RESIDUAL P CONCENTRATION VS STOICHIOMETRIC REMOVAL AT A pH OF 7.3

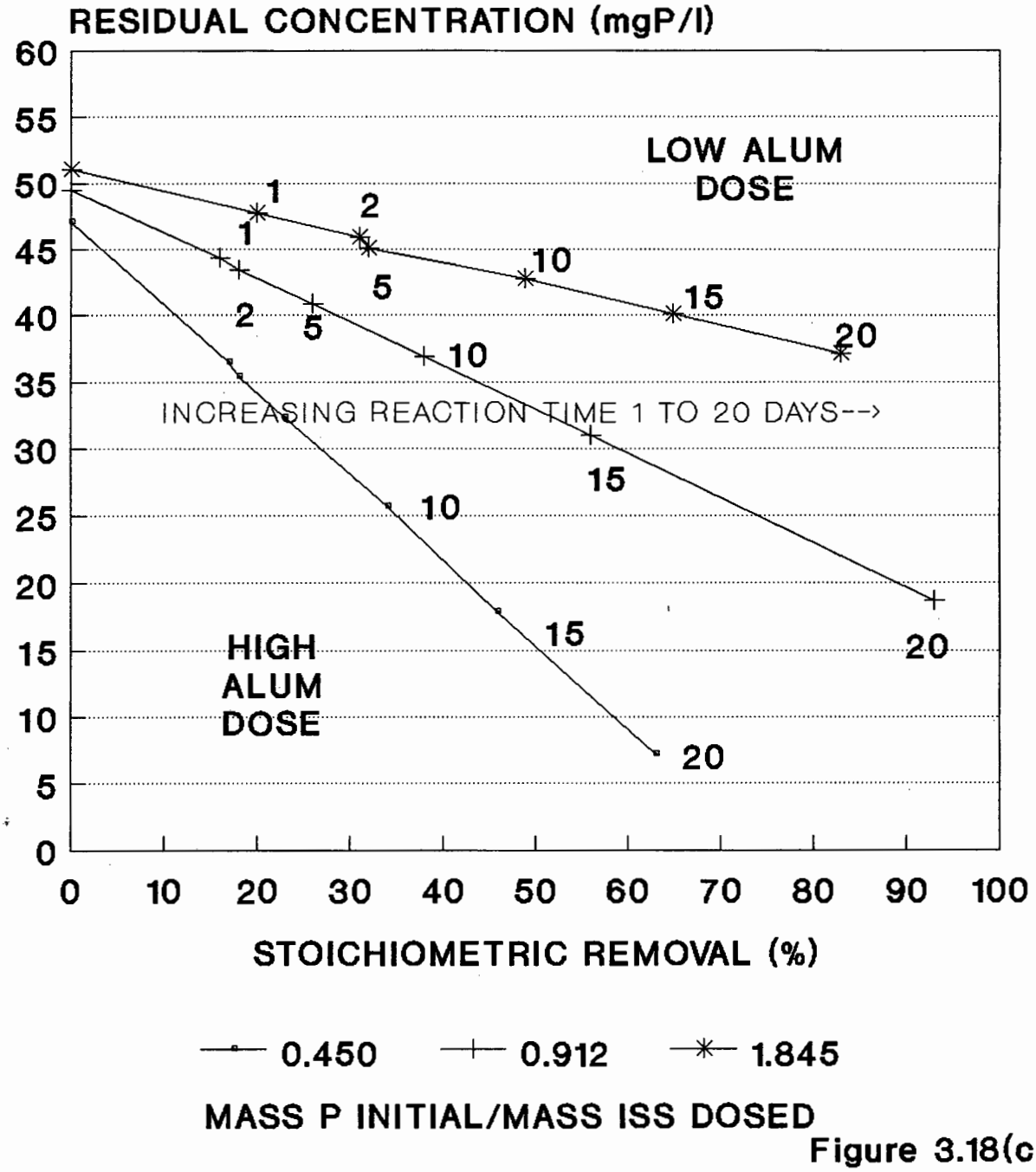
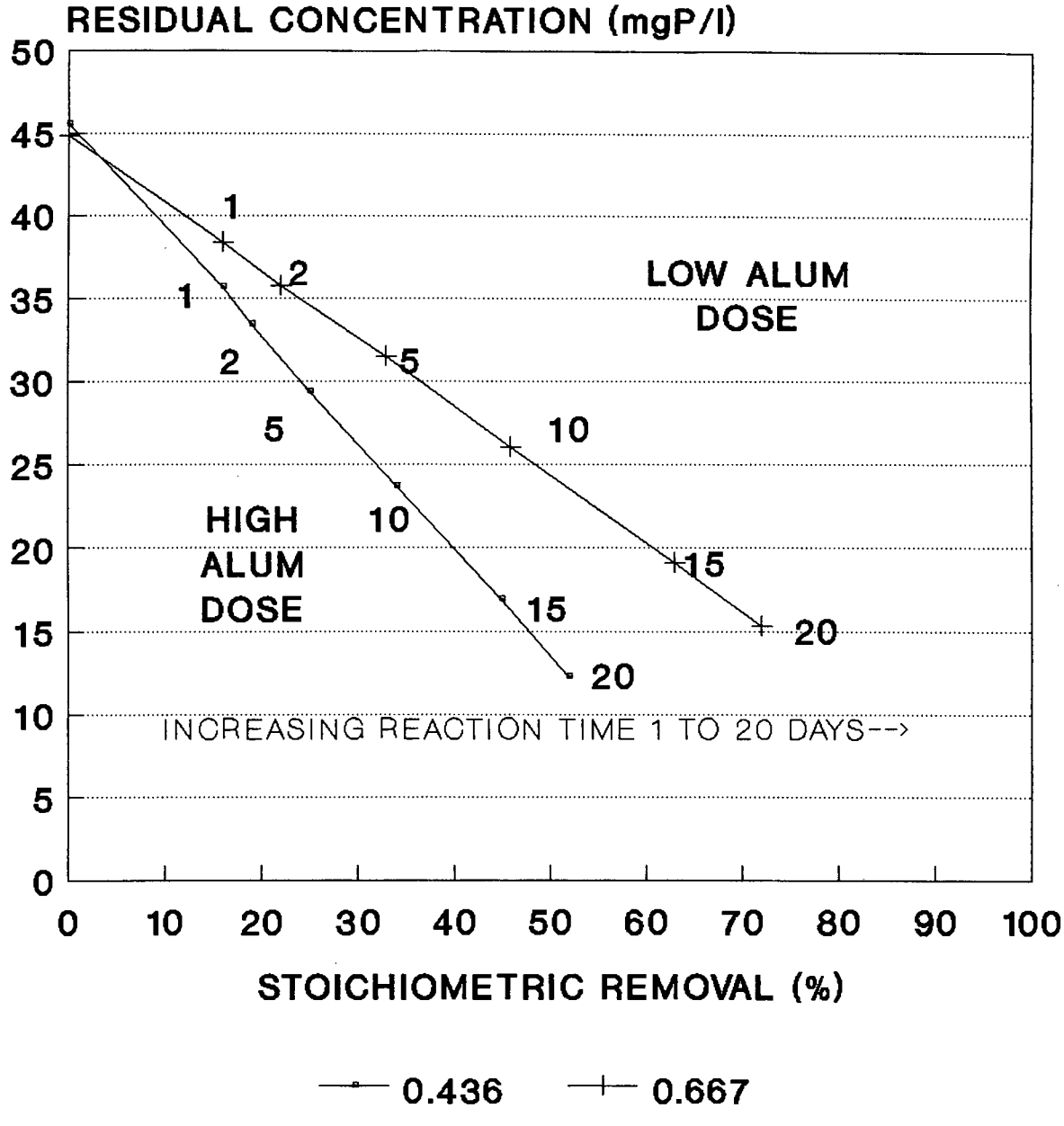


Figure 3.18(c)

RESIDUAL P CONCENTRATION VS STOICHIOMETRIC REMOVAL AT A pH OF 7.5



0.436 0.667

MASS P INITIAL/MASS ISS DOSED

Figure 3.18(d)

RESIDUAL P CONCENTRATION VS STOICHIOMETRIC REMOVAL AT A pH OF 7.8

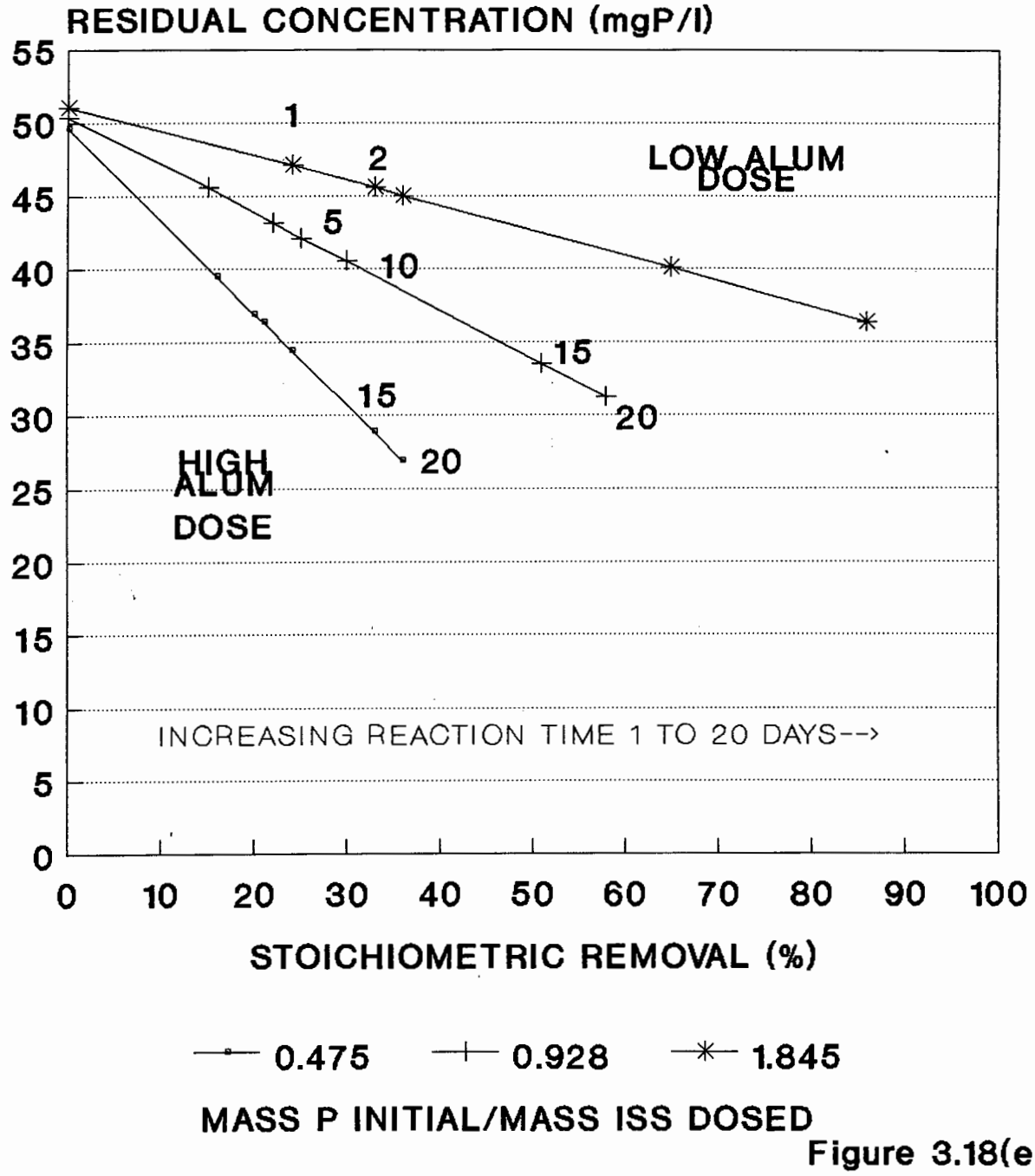


Figure 3.18(e)

Because there appeared to be a relationship between the dosing ratio and percentage stoichiometric removal from Figure 3.18, a graph of % stoichiometric removal vs the log of dosing ratio (initial P mass/mass ISS dosed) was plotted for the batch test data at a reaction time of 20 days. (See Fig 3.19). From Fig 3.19 it can be seen that apart from the anomalous data points described earlier, reasonably straight line plots are obtained. Figure 3.19 also shows that the % stoichiometric removals achieved in the ranges 6.8 to 7.0 and 7.3 to 7.5 are similiar and this allows the values in these two ranges to be grouped together. The linear regression function provided in QUATTRO was used to fit an equation to the regrouped data and the results of the regression analysis is summarized below (for details see Appendix E):

<u>pH range 6.8 to 7.0:</u>

Percentage stoichiometric removal at 20 days (%) =
96,05 x log(mgP initial/mgISS dosed) + 101,2

This equation is the result of 7 observations and has a correlation coefficient of 0,92, which indicates a good fit.

<u>pH 7.3 to 7.5:</u>

Percentage stoichiometric removal at 20 days (%) =
109,69 x log(mgP initial/mgISS dosed) + 95,31

This equation is the result of 4 observations and has a correlation coefficient of 0,93, again indicating a good correlation.

<u>pH 7.8:</u>

Percentage stoichiometric removal at 20 days (%) =
84,89 x log(mgP initial/mgISS dosed) + 62,53

This equation is the result of 3 observations and has a correlation coefficient of 1,00.

These observations seem to indicate that, the percentage stoichiometric removal decreases as the dosage ratio (initial P mass/ISS mass dosed) decreases, ie the more alum added, the lower the percentage stoichiometric removal

STOICHIOMETRIC REMOVAL VS INITIAL P MASS/ISS MASS DOSED AFTER 20 DAYS

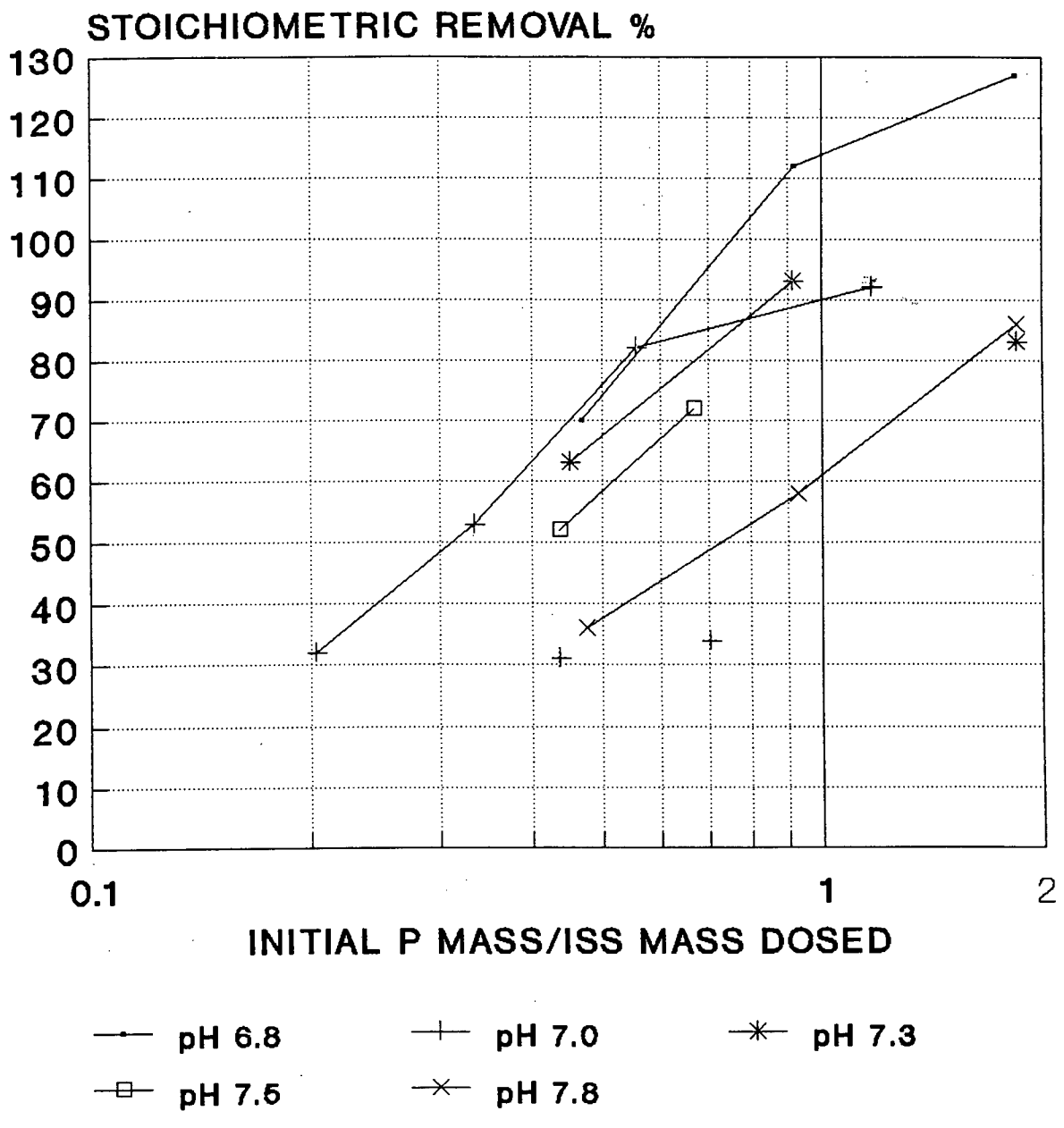


Figure 3.19

3.6.2 Phosphorus removal using unused commercial aluminium sulphate in stirred jar batch tests

In order to compare the P precipitation ability of the alum sludge with that of unused commercial alum, a series of 3 stirred jar batch tests with commercial grade alum were conducted at a controlled pH of 7.0 and final batch volume of 500ml. The initial P mass, the mass of Al dosed (calculated from the mass of alum added), the equivalent ISS mass of the alum dosed and the mass of P removed after 1, 2, 5, 10, 15 and 18 days are given in Table 3.19. The equivalent ISS mass of the alum dosed was calculated with the earlier derived relationship between ISS and Al of 0.53 mgAl/mgISS for alum sludge (see section 3.3), a relationship which also applies to commercial alum, eg if 666mg$Al_2(SO_4)_3.18H_2O$ are added to distilled water, 54 mgAl is dosed. The Al in water forms insoluble hydroxide flocs. If the water is then dried off completely at 105 C and the residue incinerated at 550 C the ash that remains will all be Al_2O_3. Hence the Inorganic Suspended Solids (ISS) of 54 mgAl is the Al_2O_3 mass of 102 mgISS yielding an Al/ISS ratio of 0.53 mgAl/mgISS.

Table 3.19: **Initial phosphorus mass, mass Al added, equivalent ISS mass and phosphorus removed after 1, 2, 5, 10, 15, and 20 days in stirred jar batch tests using commercial aluminium sulphate**

pH & No	Init. P mass	Mass Al added	Equiv ISS mass	Mass of phosphorus removed (mgP) after					
				1	2	5	10	15	18
	mgP	mgAl	mgISS	days					
7.0									
18	23.38	28.54	53.97	5.05	na	13.06	18.80	22.56	22.73
19	23.53	17.84	33.72	10.82	9.98	11.47	18.76	21.94	22.74
20	23.38	10.70	20.23	8.19	9.16	6.63	13.88	17.63	20.69

Table 3.20: Initial phosphorus mass, mass Al added, equivalent ISS mass and P removed after 1,2,5,10, 15 and 20 days in stirred jar batch tests using commercial aluminium sulphate.

pH & Test No.	Init. conc. mgP/l	Equiv ISS mass dosed mgISS	Residual P concentration (mgP/l) & stoichiometric removal (%) after						Dosing ratio P init./ ISS dosed mgP/mgISS
			1	2	5	10	15	18	
			days.						
7.0									
18	44.11	53.97	34.59	na	19.47	8.64	1.54	1.23	0.433
			15%	--	40%	57%	69%	69%	
19	45.68	33.72	24.67	na	23.42	9.26	3.08	1.54	0.698
			53%	--	56%	92%	107%	111%	
20	46.30	20.23	30.08	na	30.15	18.82	11.39	5.32	1.156
			67%	--	66%	113%	143%	168%	

The alum jar test data were manipulated in the same manner as the alum sludge jar test data. In Fig 3.20, the alum data are plotted mass P removed versus time with the initial P mass also shown (as a dark horizontal line). The percentage stoichiometric removal at 1, 2, 5, 10, 15 and 18 days was calculated and tabulated together with the residual P concentration in Table 3.20 and in Fig 3.21 the residual P concentration is plotted versus % stoichiometric removal. As with the alum sludge data, so the alum data show a linear relationship between residual P concentration and percentage stoichiometric removal in Fig 3.21 even at low residual P concentrations (<5 mgP/l) and like for the alum sludge jar tests, it was concluded that P removal behaviour was not influenced by P limitation.

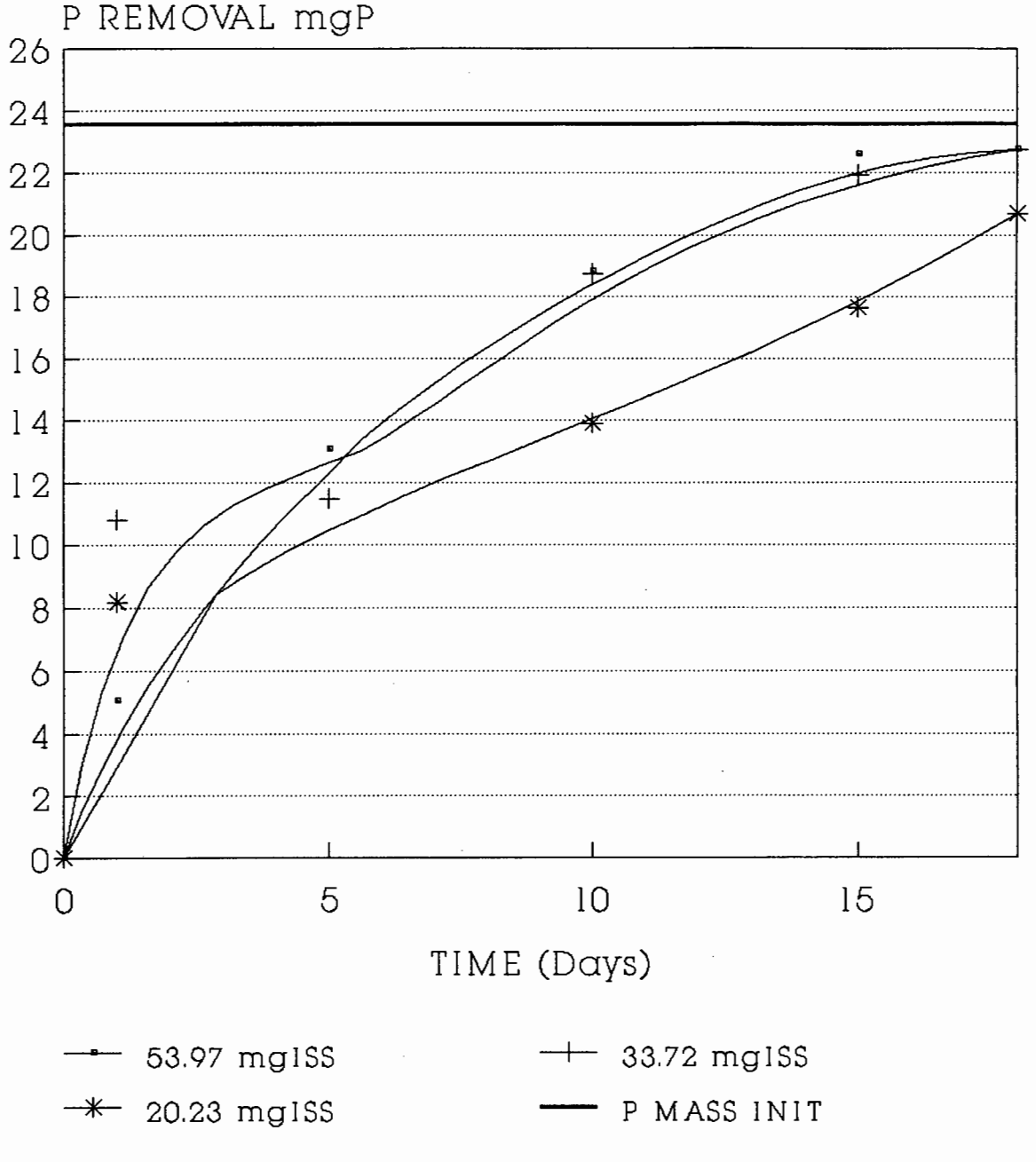
Accepting the form of the relationship between % stoichiometric removal and the log of the initial P/ISS mass dose ratio, the alum data yields:

Percentage stoichiometric removal after 18 days (%) =

$$232{,}40 \times \log(\text{P initial/Equiv. ISS mass dosed}) + 151{,}38$$

The above equation fitted to the 3 alum jar tests yielded a correlation coefficient of 0,995. The data as well as the equations are shown plotted in Fig 3.22.

MASS OF P REMOVED VS REACTION TIME AT A pH OF 7.0 USING COMMERCIAL ALUM



ISS MASS DOSED

BATCH VOLUME = 0.500 litres

Figure 3.20

RESIDUAL PHOSPHORUS CONCENTRATION VS STOICHIOMETRIC REMOVAL AT A pH OF 7.0 USING COMMERCIAL ALUM

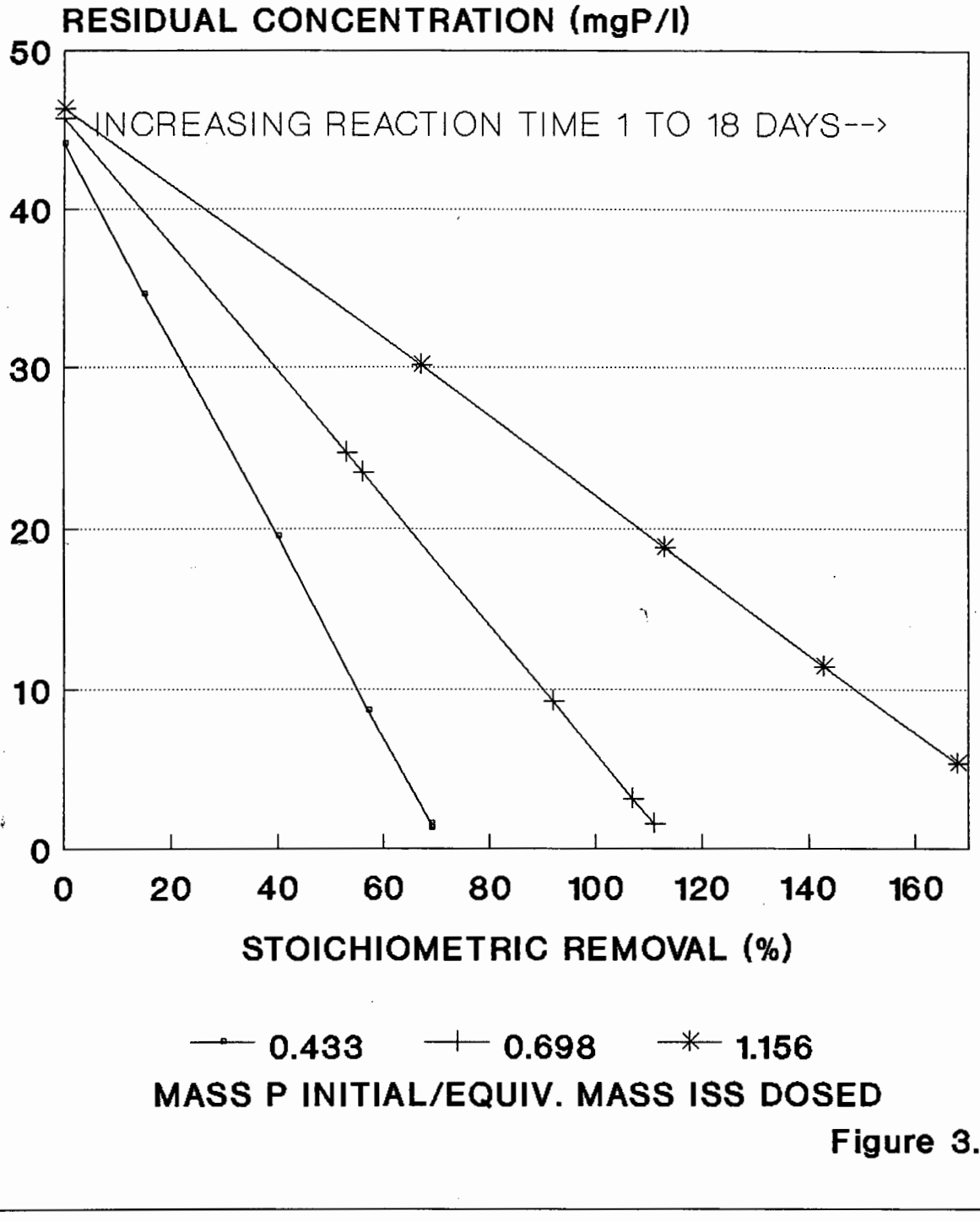


Figure 3.21

STOICHIOMETRIC REMOVAL VS INITIAL P MASS/ISS MASS DOSED

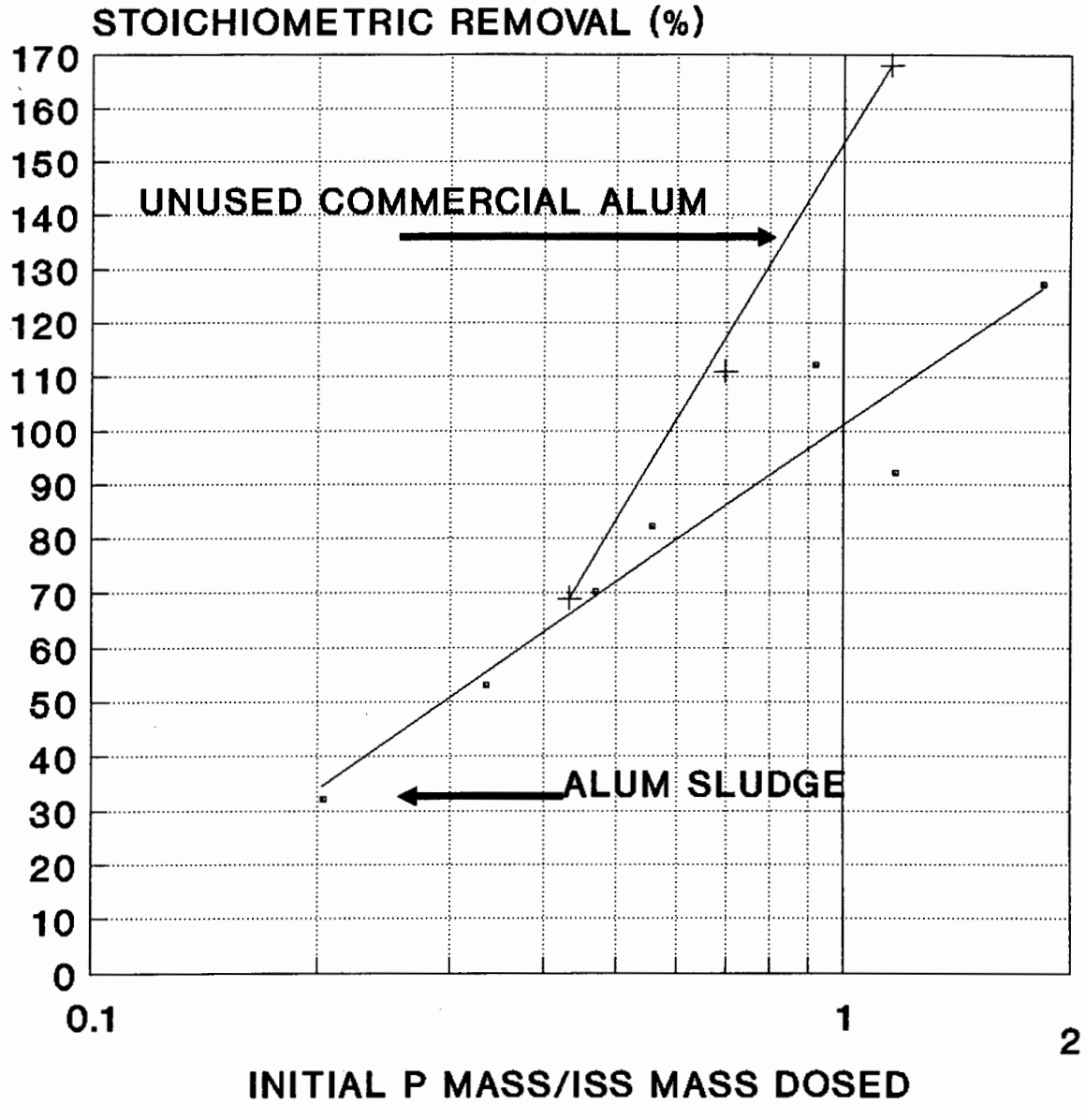


Figure 3.22

3.6.3 Comparison between P removal by alum sludge and aluminium sulphate

In order to compare the P removal by alum and alum sludge, the percentage stoichiometric removal vs dosing ratio in terms of ISS dosed on a logarithmic scale have been plotted in Fig 3.22 also for the batch tests on alum sludge in the pH range 6.8 to 7.0. It can be seen from Fig 3.22 that the alum exhibited a greater propensity to remove phosphorus than alum sludge when the ratio of initial phosphorus to initial equivalent ISS was high whereas under low initial P/ISS mass dose ratios a similiar removal is observed.

This observation indicated that the comparison of alum sludge and alum should be made not only at similiar pH values but also at similiar equivalent ISS dosage ratios ie batch tests 9 and 18 should be compared. This is done in Fig 3.23 which shows that not only is the % stoichiometric removal versus time similiar for the alum and alum sludge, but also the ultimate percentage stoichiometric removal at 20 days ie approximately 70%.

The similiarity of alum and alum sludge P removal behaviour at low dosing ratios (Fig 3.23) demonstrates that the P precipitation propensity of the alum has not been adversely influenced by it having been used as a coagulant in sweep coagulation with brown colour waters, and behaves similiarly as used alum at the same low dosage ratios and pH. This similiarity of behaviour at low dosage ratios (initial mass P/ISS mass dosed) ie under excess Al concentrations using both unused alum and alum sludge, appears to indicate that the aluminium species predominating under these conditions is aluminium hydroxide.

STOICHIOMETRIC REMOVAL VS TIME FOR COMMERCIAL AND ALUM SLUDGE AT A pH OF 7.0

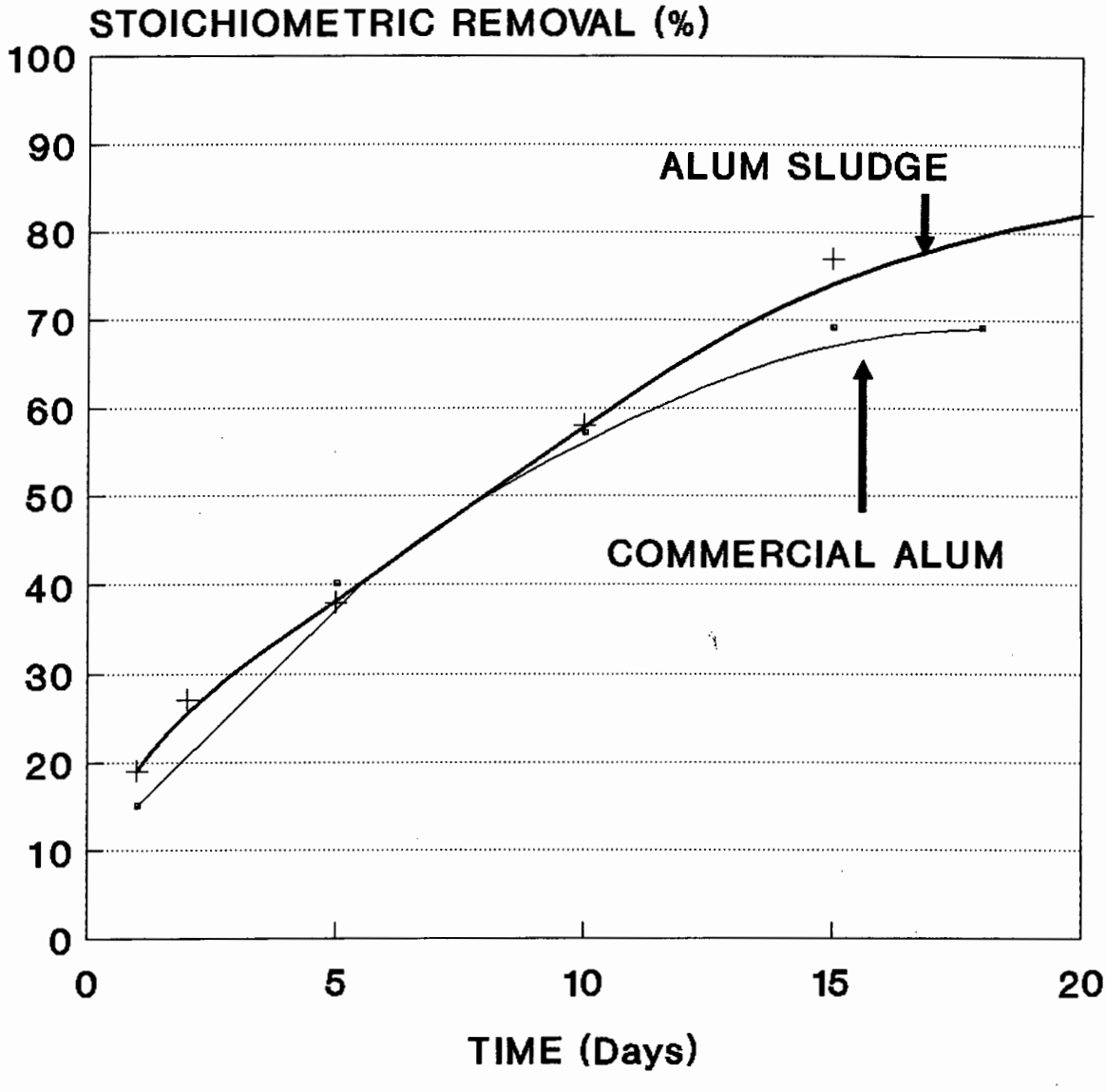


Figure 3.23

3.6.4 Change in alkalinity and the precipitation mechanism in stirred jar batch tests.

Hydrochloric acid was added to the stirred jar batch tests to control the pH at the preselected values. Table 3.21 lists the total volume of acid added to the stirred jar batch tests to control the pH over the test period, the Normality of this acid, the mass of phosphorus removed. The molar ratio between the moles of hydrogen ions added and moles of phosphorus removed was calculated as demonstrated below and is also listed in Table 3.21.

Moles of protons (H^+) required to maintain required pH value =

Normality * volume of acid added (l)

Moles of phosphorus removed =

P mass removed (g)/Molecular mass of P

= mass of P removed (g)/32

Table 3.21: **Total amount of acid added to stirred jar batch tests and molar ratios H added/P removed after 20 days**

Batch test No.	pH controlled at	Volume 0.6335N acid added. ml.	Mass of phosphorus removed at 20 days. mgP	Molar ratio H added/ P removed mol/mol
6	7.0	1.04	11.68	1.75
7	7.0	0.83	11.20	1.45
8	7.0	0.75	10.34	1.42
13	7.5	0.91	17.59	1.02
14	7.5	0.91	15.18	1.18
*18	7.0	8.50	22.56	7.29
*19	7.0	5.64	22.74	4.83
*20	7.0	3.55	20.69	3.37

* Commercial aluminium sulphate was used as a precipitant for these stirred jar batch tests. These tests were only run for 18 days.

As mentioned in section 3.5.10 above at a pH of around 7.2, the phosphate species are in the $H_2PO_4^-$ and HPO_4^{2-} form and approximately at equal concentrations. In its HPO_4^{2-} form 2 moles of OH^- will be released upon $AlPO_4$ precipitation and in its H_2PO_4 form only 1 mole of OH^-. So at a pH of 7.2 where H_2PO_4 and HPO_4 are at approximately equal concentrations, the alkalinity increase or equivalently the moles H^+ added to maintain constant pH, per mole P precipitated can be expected to be about 1.5 moles H^+/mole P precipitated.
At lower pH values, lower molar ratios are expected because the lower the pH the greater the $H_2PO_4^-$ concentration and lower the HPO_4^{2-} concentration, leading to less OH^- release on $AlPO_4$ precipitation. From the average molar ratio in Table 3.21, approximately 2.1mg/l as $CaCO_3$ alk is produced per mgP precipitated. While this is an alk increase, it is clearly neglible in comparison with the alkalinlity changes that take place with nitrification and denitrification, where the nitrification of 40mgN/l NH_4^+ to NO_3^- reduces the alkalinity by 7.14 x 40 = 286 mg/l as $CaCO_3$ and denitrification of 40mgN/l nitrate increases the alkalinity by 3.57 x 40 = 143 mg/l as $CaCO_3$. The reactions using aluminium sulphate are more complex and as seen in Table 3.21 require much larger amounts of acid to control the pH.

3.7 COMPARISON BETWEEN THE P PRECIPITATION WITH ALUM SLUDGE IN THE EXPERIMENTAL SYSTEM AND IN THE STIRRED JAR BATCH TESTS

Because good correlations were established in Sections 3.6.1 and 3.6.2 between the dosing ratio in terms of initial P mass to mass of ISS dosed and percentage stoichiometric removal, Table 3.22 was drawn up listing for each of the fifteen steady state periods:

(A) the initial P mass in the Experimental system available for precipitation which was taken as being equal to the mass of P in the effluent from the Control system; *

(B) the alum sludge ISS mass dosed daily;

(C) the dosing ratio mgP initial/mgISS dosed (ie A divided by B);

(D) the percentage stoichiometric removal achieved in the Experimental system;

(E) the stoichiometric removal expected from the alum sludge stirred jar tests at the same pH as that in the Experimental system (ie at a pH of 7.8) calculated from the equation presented in Section 3.6.1 above;

(F) the ratio as a percentage between the actual percentage stoichiometric removal observed in the Experimental system (D) and that expected in the alum sludge stirred jar tests (E) (ie D/E x 100).

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*
The mass of P available for precipitation in the Experimental system is equal to influent P mass minus the P mass removed biologically. The biologically removed mass of P was calculated from the difference between the influent and effluent P masses of the Control system, and because both the Control and Experimental systems recieved the same influent P mass, the P available for precipitation in the Experimental system is equal to the effluent P mass of the Control system.

Table 3.22: Initial phosporus mass, alum ISS dosed, dosing ratio (P_{init}/mg ISS dosed), stoichiometric removal due to alum dosing in Experimental system for steady state periods 1 to 15, expected stoichiometric removal in stirred jar batch tests at pH = 7,8, and removal in Experimental system as a % of that expected in the jar tests.

Steady State Period	Initial P mass mgP (A)	mgISS dosed (B)	Dosing ratio mgP/ mgISS (C)	Stoich removal in Exp. system % (D)	Stoich removal in jar test @ pH 7.8 (E)	Removal in Exp. system as % of jar test (F)
1	200	173	1.156	20	68	29
2	213	173	1.234	28	70	40
3	213	189	1.127	30	67	45
4	212	212	1.000	22	63	35
5	214	212	1.009	33	63	52
6	218	212	1.028	32	64	50
7	226	212	1.066	37	65	57
8	212	415	0.511	19	38	50
9	220	424	0.519	28	38	74
10	215	424	0.507	29	37	78
11	238	227	1.048	31	64	48
12	219	227	0.965	35	61	57
13	82	226	0.363	24	25	96
14	89	491	0.181	14	-	-
15	59	491	0.120	12	-	-

The percentage stoichiometric removals achieved in the Experimental system and the jar tests at a pH of 7.8 after 20 days are plotted against the log of the dosing ratio in Figure 3.24. It can be seen from Figure 3.24 that the percentage stoichiometric removals achieved in the Experimental system are much lower than those obtained in the jar tests particularly at the higher dosing ratios. It can also be seen that the maximum percentage stoichiometric removal in the Experimental system is achieved at a dosing ratio of approximately 1 mgP initial/mgISS dosed.

COMPARISON BETWEEN STOICHIOMETRIC REMOVAL VS INITIAL P/ISS MASSES DOSED IN EXP. SYSTEM AND JAR TEST AT pH 7.8

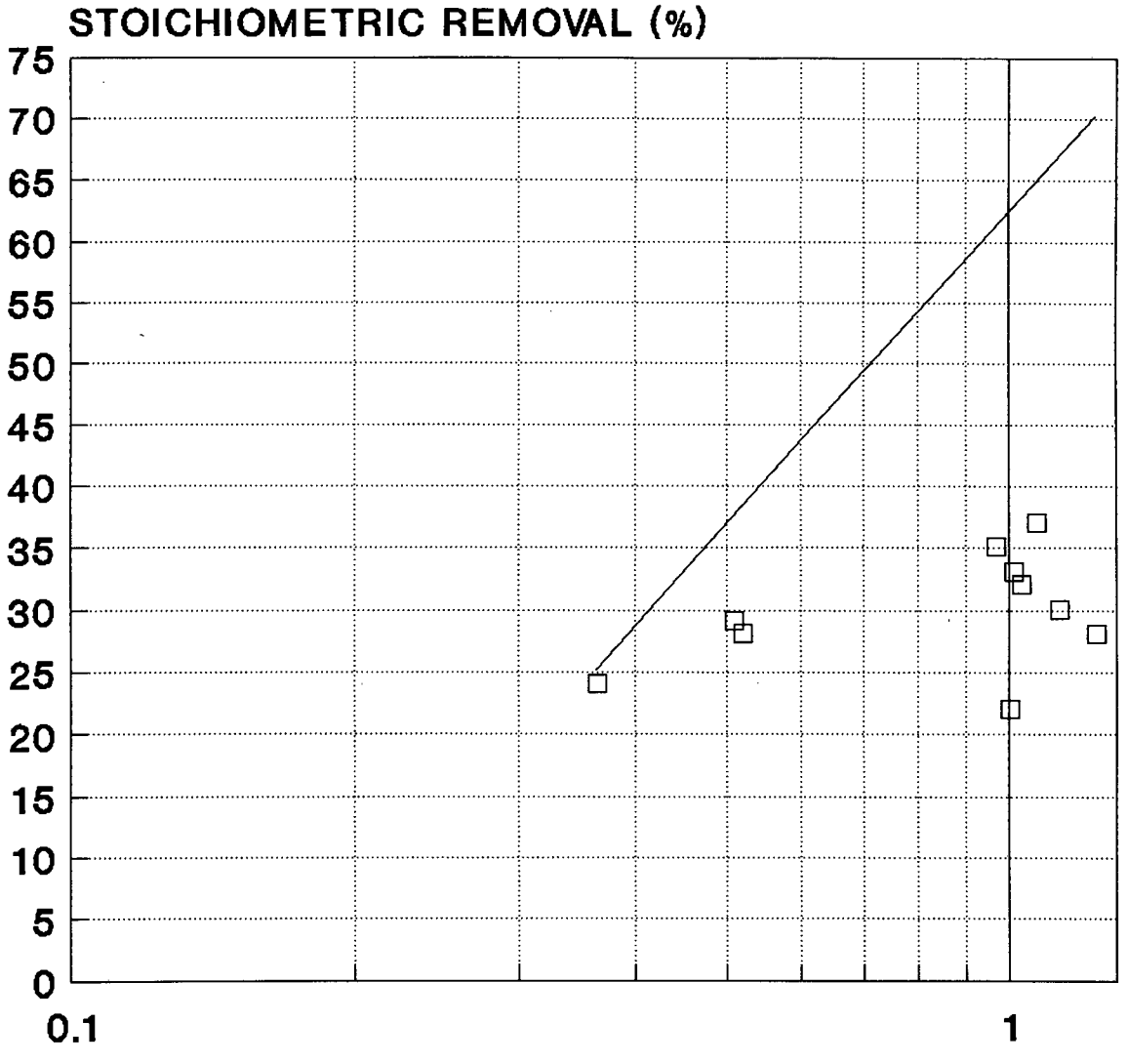

Figure 3.24

At a dosing ratio of 1 mgP initial/mgISS dosed, approximately one third stoichiometric removal is achieved in the Experimental system, whereas about two thirds stoichiometric removal is achieved in the jar tests. The difference in the P removals achieved in the Experimental system and jar tests probably arises from the different hydraulic regimes in the Experimental system and jar tests. The jar tests are batch reactors wherein the dissolved P concentrations remained in contact with the solid alum sludge for a period of 20 days. In contrast the Experimental system was a flow through system where the dissolved P concentration remained in contact with the solid alum sludge mass for an average as long as the nominal hydraulic retention time ie 1 day. However due to the accumulation of alum sludge in the system, the P removal from the Experimental system is much better than a batch retention time of 1 day; one third stoichiometric removal at a pH of 7.8 and a dosage ratio of 1 mgP initial/mgISS dosed is achieved at about 10 days batch retention time.

CHAPTER 4

CONCLUSIONS FROM THE RESEARCH

The gelatinous nature of alum sludges from waterworks makes them difficult to dewater and dispose of, and mechanical methods are generally required to achieve a solids concentration suitable for landfills. In this investigation, an alternative novel alum sludge disposal method is examined, namely the disposal of alum sludges into activated sludge plants treating municipal sewage.

The effect of alum sludge disposal on activated sludge plants was examined by comparing the results obtained from two laboratory scale Modified Ludzack Ettinger (MLE) predenitrification systems receiving 10 l/day unsettled municipal wastewater as influent at a controlled concentration of 500 mgCOD/l. The two systems were operated for a period of 310 days at a sludge age of 20 days. During this time one system, the Experimental, was dosed with a measured mass of alum sludge on a daily batch basis, dosage varying between 173 mg inorganic solids (mgISS/d) and 491 mgISS/d which is equivalent to 17,3 and 49,1 mgISS/l influent flow. The second system acted as a Control against which the performance of the Experimental system was evaluated. The alum sludges dosed during the investigation were produced at Kloof Nek and Steenbras water treatment works which treat the brown waters of the Western Cape.

The total suspended solids (TSS) of the alum sludges used in the investigation averaged 61% organic (volatile), 39% inorganic (ash), 0,005 mgN/mgTSS and 0,61 mgCOD/mgTSS. Originating from the treatment of low alkalinity waters, the ash content of the alum sludge for all practical purposes consists entirely of Al_2O_3, which enables the Al content of these sludges to be expressed as 0,53 mgAl/mgISS or 0,20 mgAl/mgTSS.

The ability of alum sludge and unused commercial alum to remove phosphorus was also investigated in a series of stirred jar batch tests operated for 20 days at preselected pH values ranging from 6.8 to 7.8. The results obtained in these tests were compared with the P removals attributed to alum dosing in the Experimental system.

4. COD removal from the wastewater, and nitrification and denitrification in the activated sludge plant were not affected by alum sludge dosing. The similarity of COD removal could not be assessed on the basis of effluent COD, due to alum sludge COD in the effluent (see 2 above). This was established from the oxygen utilisation rate, and nitrate removal and denitrification rates. These were the same in both Experimental and Control systems. The effluent TKN was unchanged with alum dosing, indicating that alum sludge did not negatively influence nitrification.

5.0. Phosphorus removal in the activated sludge plant imcreased with the addition of alum sludge. At steady state, the alum sludge stimulated a P removal of 0.18 mgP/mgISS added when the pH of the mixed liquor averaged 7,6. Accepting for the alum sludge obtained from the treatment of Western Cape soft waters that the ISS is entirely Al_2O_3, then the removal is one third of the stoichiometric removal ratio for the Al in the alum sludge i.e. a percentage stoichiometric removal ratio of 33%.

5.1 Results obtained in stirred jar batch tests indicated that percentage stoichiometric P removal after 20 days (i.e. the sludge age of the activated sludge system), is dependant on the dosing ratio, i.e. initial P mass/Al mass added, as well as pH. In the presence of excess P, the percentage stoichiometric P removal deteriorated under excess aluminium conditions.

5.2. The percentage stoichiometric P removal achieved in stirred jar batch tests with unused alum and alum sludge, were similiar when compared at similiar initial P mass/ISS mass dosed ratios and pH values, verifing the Al/ISS ratio for the Western cape alum sludges as being 0,53 (see 5.0 above).

The dewaterability of the activated sludge in the Control and Experimental systems as well as the effect on dewaterabilty of mixing alum sludge directly with various municipal sludges was examined in a series of Specific Resistance to Filtration (SRF) and Capillary Suction Time (CST) tests.

The following conclusions can be drawn from the investigation:

1. The VSS of the alum sludge was not biodegradable and accumulated with the activated sludge in the biological reactor in proportion to the dosing rate.

2. The COD and TKN of the alum sludge is unbiodegradable, 51% of the COD escaping with the effluent as soluble unbiodegradable material, giving the effluent a brownish colour due to humic and fulvic acids. The turbidity of the effluent was around 8 NTU compared to 3 NTU from the Control system. None of the alum sludge TKN appeared to escape with the effluent.

3. Alum sludges have poor dewatering characteristics, yielding SRF and CST values of 70×10^{12} m/kg and 25 seconds respectively. However, the values for the alum/activated sludge mixture (45% of the TSS being alum sludge TSS) was the same as that for the activated sludge only, ie 20×10^{12} m/kg, indicating that the dewaterability of the alum sludge is improved during its retention in the activated sludge reactor. This improvement is not obtained by simply mixing the two sludges; if this is done the mixture simply takes on the dewatering characteristics of the constituent sludges, the value obtained being dependant on the relative amounts and dewaterability of the constituent sludges. The improvement in dewaterability of the alum sludge in the activated sludge plant arises from the exchange of the OH^- with PO_4^{3-} on the Al thereby changing the gelatinous $Al(OH)_3$ to an $AlPO_4$ precipitate.

4. COD removal from the wastewater, and nitrification and denitrification in the activated sludge plant were not affected by alum sludge dosing. The similarity of COD removal could not be assessed on the basis of effluent COD, due to alum sludge COD in the effluent (see 2 above). This was established from the oxygen utilisation rate, and nitrate removal and denitrification rates. These were the same in both Experimental and control systems. The effluent TKN was unchanged with alum dosing, indicating that alum sludge did not negatively influence nitrification.

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5.1 Results obtained in stirred jar batch tests indicated that percentage stoichiometric P removal after 20 days (i.e. the sludge age of the activated sludge system), is dependant on the dosing ratio, i.e. initial P mass/Al mass added, as well as pH. The percentage stoichiometric P removal deteriorated under excess aluminium conditions.

5.2. The percentage stoichiometric P removal achieved in stirred jar batch tests with unused alum and alum sludge, were similiar when compared at similiar initial P mass/ISS mass dosed ratios and pH values, verifing the Al/ISS ratio for the Western cape alum sludges as being 0,53 (see 5.0 above).

5.3. At the same batch retention time and sludge age (20 days), the stirred jar batch tests do not accurately predict the expected P removal to be achieved in an activated sludge plant with alum sludge dosing. The batch test removal at 20 days was approximately two thirds stoichiometric, whereas in the activated sludge system at a 20 day sludge age it was only one third stoichiometric. This difference arises from the different liquid/sludge contact times between the batch and activated sludge sludges, which in the latter case was only 24 hours, because of the different flow regimes for the two systems.

6. The alum/activated sludge mixture settled slightly better than activated sludge alone. The systems were started up with a low F/M filament bulking sludge with a DSVI of 250 ml/g, but over 200 days of operation this gradually declined to below 100 ml/g in both systems with M. parvicella disappearing from the systems. Installing a mixed liquor (a) recycle of 4:1 from the aerobic to anoxic reactor of the Control system, caused the DSVI to increase over 40 days, the causative filament apparently being H. hydrossis, and the removal of recycle caused the DSVI to decrease. However, repeating the change on the Experimental system did not stimulate this increase, and the DSVI remained at around 100 ml/g. For the last 100 days of the investigation 021N appeared in the sludges. This was attributed to septic sewage feed and once eliminated these filaments declined. In general the addition of alum sludge did not adversely affect the settleability of the sludge. Low F/M filaments did not proliferate in the 2 reactor ND systems and the absence of M. parvicella, a filament dominant in intermittent systems, was notable.

7. Although dosing of alum sludge did not affect sludge settleability in terms of DSVI, it does require larger settling tanks by virtue of the increased reactor TSS concentration it produces.

SPBP/September1992.

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APPENDIX A:

WATER TREATMENT DATA FROM CAPE TOWN CITY ENGINEER'S ANNUAL REPORT

TABLE 9: WATER TREATMENT DATA

Supply		Constantia Nek	Klool Nek	Steenbras	Wemmershoek	Voëlvlei	Blackheath
Nature of Treatment		Coagulation settlement filtration liming carbonation	Coagulation settlement filtration liming carbonation	Coagulation settlement filtration liming carbonation	Coagulation filtration liming carbonation chlorination	Coagulation settlement filtration chlorination	Coagulation settlement filtration liming carbonation
Water Treated	m^3/h	116	500	4 375	7 708	4 792	7 667
Sedimentation period	h	2.0	5.4	2.8	-	5.7	2.5
Filtration rate	m/h	4.0	3.4	4.5	6.0	3.4	5.1
Chemical dosage — mg/l:							
Ferric sulphate as Fe		-	-	-	-	3.4	-
Aluminium sulphate		58.1	58.2	27.4	4.0	-	31.3
Sodium Aluminate		11.2	9.7	4.7	-	-	-
Lime		47.2	41.2	30.2	25.2	15.6	31.0
Chlorine		2.7	2.4	2.3	1.6	2.8	1.8
Coke		12.0	8.4	9.2	9.8	-	10.0

Chemical analysis (mg/l average unless otherwise indicated)		Raw	Treated	Raw	Treated	Raw	Treated	Raw	Treated	Raw	Treated	Raw	Treated
Samples examined		41	42	38	38	49	51	51	51	41	41	51	51
Electrical conductivity	mS/m	6.4	17.7	5.9	15.7	6.8	14.6	2.7	8.7	10.9	14.6	4.6	12.6
pH value		4.8	9.0	4.7	9.4	5.6	9.1	6.4	9.0	7.6	8.8	6.4	9.0
Turbidity	NTU	1.2	0.35	1.7	1.2	3.7	0.60	1.1	0.72	10.5	0.42	3.5	0.68
Colour		160	2	168	2	55	2	2	2	3	2	14	2
UV Absorbance (300 nm, 40 mm)		2.24	0.069	2.30	0.115	0.790	0.116	0.158	0.045	0.159	0.050	0.351	0.047
Oxygen absorbed		16.2	0.6	17.3	0.7	6.1	0.8	1.0	0.4	2.0	0.6	3.6	0.4
Total hardness as CaCO3		8.0	52.6	8.1	51.5	8.4	44.7	3.3	34.2	20.8	33.3	8.3	46.9
Alkalinity as CaCO3		0.0	28.3	0.0	26.2	1.7	27.3	2.0	27.1	14.1	18.9	4.8	30.4
Chloride as Cl		16.9	20.5	15.2	19.2	18.1	20.2	8.3	9.9	23.2	23.7	10.4	13.6
Sulphate as SO4		2.5	24.5	2.6	23.2	3.5	13.3	1.0	3.4	4.4	11.7	2.6	14.0
Calcium as Ca		1.5	18.6	1.6	17.1	1.6	15.4	0.6	11.3	4.0	9.6	2.1	16.1
Magnesium as Mg		2.06	1.83	1.35	2.31	1.79	1.75	1.02	0.81	3.63	3.60	1.18	1.20
Sodium as Na		7.1	10.0	6.9	7.8	8.0	8.8	3.3	3.3	10.2	9.8	4.4	4.6
Potassium as K		0.36	0.35	0.51	0.51	0.41	0.36	0.20	0.21	0.79	0.63	0.47	0.44
Aluminium as Al		0.27	0.28	0.27	0.29	0.31	0.30	0.10	0.17	0.42	0.08	0.63	0.14
Iron as Fe		0.164	0.023	0.208	0.044	0.436	0.032	0.098	0.050	0.511	0.017	0.473	0.026
Manganese as Mn		0.014	0.014	0.021	0.024	0.020	0.020	0.030	0.049	0.017	0.002	0.018	0.019
Bacteriological data: (95 percentiles)													
Samples examined			42		35		51		52		40		52
Faecal coliforms	/100 ml		1		1		1		1		1		1
Total plate count	/ml		1		1		1		1		2		1

APPENDIX B:
MASS BALANCES

APPENDIX B

MASS BALANCE ON CONTROL SYSTEM FOR STEADY STATE PERIOD 1 (DAYS 59-73)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.96 LITRE/DAY

OBSERVED PARAMETERS. fcv= 1.48
fn= 0.1

INFLUENT COD= 564 mgCOD/l
INFLUENT TKN= 54.1 mgN/l
INF. NITRATE= 438 mgN/d
EFFLUENT COD= 57 mgCOD/l
EFFLUENT TKN= 3.3 mgN/l
EFFLUENT NITRATE= 23.3 mgNO3-N/l
AEROBIC NITRATE= 23.3 mgNO3-N/l
ANOXIC NITRATE= 4.2 mgNO3-N/l
MLVSS= 2107 mgVSS/l
MEASURED OUR= 33 mgO/l/h
NITROGEN BALANCE:
NITTRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 583.5968 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1669 mgO/d
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 105.35 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE= 979 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 954.9468 mgN/d
NITROGEN BALANCE= 97.5 '%

NITRATE PRODUCED FROM TKN = INF TKN - EFF TKN - TKN WASTED
399.482 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 401 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 400 *4.57 = 1833 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 2376 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 543 mgO/d

COD INPUT TO SYSTEM = 5640 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION =
COD BALANCE = 78 '%

APPENDIX B

MASS BALANCE ON CONTROL SYSTEM FOR STEADY STATE PERIOD 2 (DAYS 74-86)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.96 LITRE/DAY

OBSERVED PARAMETERS. fcv= 1.48
fn= 0.1

INFLUENT COD= 520 mgCOD/l
INFLUENT TKN= 36.9 mgN/l
INF. NITRATE= 481 mgN/d
EFFLUENT COD= 56 mgCOD/l
EFFLUENT TKN= 3.3 mgN/l
EFFLUENT NITRATE= 14.3 mgNO3-N/l
AEROBIC NITRATE= 14.3 mgNO3-N/l
ANOXIC NITRATE= 2.9 mgNO3-N/l
MLVSS= 1926 mgVSS/l
MEASURED OUR= 24 mgO/l/h
NITROGEN BALANCE:
NITTRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 563.216 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1611 mgO/d
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 96.3 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE= 850 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 835.516 mgN/d
NITROGEN BALANCE= 98.3 %

NITRATE PRODUCED FROM TKN = INF TKN - EFF TKN - TKN WASTED
236.532 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 239 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 239 *4.57 = 1092 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 1728 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 636 mgO/d

COD INPUT TO SYSTEM = 5200 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION =
COD BALANCE = 82.4 %

APPENDIX B

MASS BALANCE ON CONTROL SYSTEM FOR STEADY STATE PERIOD 3 (DAYS 87-106)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.92 LITRE/DAY

OBSERVED PARAMETERS. fcv= 1.48
fn= 0.1
INFLUENT COD= 538 mgCOD/l
INFLUENT TKN= 49.8 mgN/l
INF. NITRATE= 459 mgN/d
EFFLUENT COD= 50 mgCOD/l
EFFLUENT TKN= 2.6 mgN/l
EFFLUENT NITRATE= 21.6 mgNO3-N/l
AEROBIC NITRATE= 23 mgNO3-N/l
ANOXIC NITRATE= 2.46 mgNO3-N/l
MLVSS= 1674 mgVSS/l
MEASURED OUR= 31 mgO/l/h
NITROGEN BALANCE:
NITTRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 623.5368 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1783 mgO/d
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 83.7 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE= 957 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 949.2368 mgN/d
NITROGEN BALANCE= 99.2 %

NITRATE PRODUCED FROM TKN = INF TKN - EFF TKN - TKN WASTED
385.908 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 400 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 400 *4.57 = 1830 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 2232 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 402 mgO/d

COD INPUT TO SYSTEM = 5380 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION =
COD BALANCE = 73.8 %

APPENDIX B

MASS BALANCE ON CONTROL SYSTEM FOR STEADY STATE PERIOD 4 (DAYS 107-121)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.98 LITRE/DAY

OBSERVED PARAMETERS, fcv= 1.48
fn= 0.1

INFLUENT COD= 530 mgCOD/l
INFLUENT TKN= 57.1 mgN/l
INF. NITRATE= 492 mgN/d
EFFLUENT COD= 47 mgCOD/l
EFFLUENT TKN= 3.2 mgN/l
EFFLUENT NITRATE= 31.3 mgNO3-N/l
AEROBIC NITRATE= 31.3 mgNO3-N/l
ANOXIC NITRATE= 8.78 mgNO3-N/l
MLVSS= 1846 mgVSS/l
MEASURED OUR= 32 mgO/l/h
NITROGEN BALANCE:
NITTRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 620.7956 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1775 mgO/d
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 92.3 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE= 1063 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 1058.0956 mgN/d
NITROGEN BALANCE= 99.5 %

NITRATE PRODUCED FROM TKN = INF TKN - EFF TKN - TKN WASTED
443.564 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 472 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 472 *4.57 = 2159 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 2304 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 145 mgO/d

COD INPUT TO SYSTEM = 5300 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION =
COD BALANCE = 71.7 %

APPENDIX B

MASS BALANCE ON CONTROL SYSTEM FOR STEADY STATE PERIOD 5 (DAYS 122-137)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.99 LITRE/DAY

OBSERVED PARAMETERS. fcv= 1.48
fn= 0.1

INFLUENT COD= 468 mgCOD/l
INFLUENT TKN= 53.7 mgN/l
INF. NITRATE= 493 mgN/d
EFFLUENT COD= 55 mgCOD/l
EFFLUENT TKN= 3.5 mgN/l
EFFLUENT NITRATE= 31.3 mgNO3-N/l
AEROBIC NITRATE= 31.3 mgNO3-N/l
ANOXIC NITRATE= 10.8 mgNO3-N/l
MLVSS= 1870 mgVSS/l
MEASURED OUR= 29 mgO/l/h
NITROGEN BALANCE:
NITTRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 579.308 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1657 mgO/d
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 93.9 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE= 1030 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 1021.208 mgN/d
NITROGEN BALANCE= 99.1 %

NITRATE PRODUCED FROM TKN = INF TKN - EFF TKN - TKN WASTED
404.635 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 430 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 430 *4.57 = 1966 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 2088 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 122 mgO/d

COD INPUT TO SYSTEM = 4680 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION =
COD BALANCE = 80.6 %

APPENDIX B

MASS BALANCE ON CONTROL SYSTEM FOR STEADY STATE PERIOD 6 (DAYS 138-157)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.83 LITRE/DAY

OBSERVED PARAMETERS. fcv= 1.48
fn= 0.1

INFLUENT COD= 507 mgCOD/l
INFLUENT TKN= 45 mgN/l
INF. NITRATE= 415 mgN/d
EFFLUENT COD= 49.3 mgCOD/l
EFFLUENT TKN= 3.4 mgN/l
EFFLUENT NITRATE= 18.3 mgNO3-N/l
AEROBIC NITRATE= 15 mgNO3-N/l
ANOXIC NITRATE= 2 mgNO3-N/l
MLVSS= 1757 mgVSS/l
MEASURED OUR= 25 mgO/l/h
NITROGEN BALANCE:
NITTRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 556.34 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1591 mgO/d
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 87.85 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE= 865 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 861.19 mgN/d
NITROGEN BALANCE= 99.6 '%

NITRATE PRODUCED FROM TKN = INF TKN - EFF TKN - TKN WASTED
325.328 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 340 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 340 *4.57 = 1552 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 1800 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 248 mgO/d

COD INPUT TO SYSTEM = 5070 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION =
COD BALANCE = 72.5 '%

APPENDIX B

MASS BALANCE ON CONTROL SYSTEM FOR STEADY STATE PERIOD 7 (DAYS 158-177)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.75 LITRE/DAY

OBSERVED PARAMETERS. fcv= 1.48
fn= 0.1

INFLUENT COD= 519 mgCOD/l
INFLUENT TKN= 57 mgN/l
INF. NITRATE= 381 mgN/d
EFFLUENT COD= 44.4 mgCOD/l
EFFLUENT TKN= 4.3 mgN/l
EFFLUENT NITRATE= 22 mgNO3-N/l
AEROBIC NITRATE= 22 mgNO3-N/l
ANOXIC NITRATE= 1.65 mgNO3-N/l
MLVSS= 1898 mgVSS/l
MEASURED OUR= 29 mgO/l/h
NITROGEN BALANCE:
NITTRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 566.7625 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1621 mgO/d
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 94.9 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE= 951 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 924.6625 mgN/d
NITROGEN BALANCE= 97.2 %

NITRATE PRODUCED FROM TKN = INF TKN - EFF TKN - TKN WASTED
428.875 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 422 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 422 *4.57 = 1930 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 2088 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 158 mgO/d

COD INPUT TO SYSTEM = 5190 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION =
COD BALANCE = 70.5 %

APPENDIX B

MASS BALANCE ON CONTROL SYSTEM FOR STEADY STATE PERIOD B (DAYS 178-193)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.78 LITRE/DAY

OBSERVED PARAMETERS. fcv= 1.48
fn= 0.1

INFLUENT COD= 497 mgCOD/l
INFLUENT TKN= 45.9 mgN/l
INF. NITRATE= 391 mgN/d
EFFLUENT COD= 44.8 mgCOD/l
EFFLUENT TKN= 4.6 mgN/l
EFFLUENT NITRATE= 21.4 mgNO3-N/l
AEROBIC NITRATE= 21.4 mgNO3-N/l
ANOXIC NITRATE= 6.05 mgNO3-N/l
MLVSS= 1833 mgVSS/l
MEASURED OUR= 31 mgO/l/h
NITROGEN BALANCE:
NITRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 479.281 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1371 mgO/d
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 91.65 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE= 850 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 830.931 mgN/d
NITROGEN BALANCE= 97.8 %

NITRATE PRODUCED FROM TKN = INF TKN - EFF TKN - TKN WASTED
317.762 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 319 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 319 *4.57 = 1458 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 2232 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 774 mgO/d

COD INPUT TO SYSTEM = 4970 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION =
COD BALANCE = 80.2 %

APPENDIX B

MASS BALANCE ON CONTROL SYSTEM FOR STEADY STATE PERIOD 9 (DAYS 194-220)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.82 LITRE/DAY

OBSERVED PARAMETERS. fcv= 1.48
fn= 0.1

INFLUENT COD= 505 mgCOD/l
INFLUENT TKN= 48 mgN/l
INF. NITRATE= 409 mgN/d
EFFLUENT COD= 60.2 mgCOD/l
EFFLUENT TKN= 3.3 mgN/l
EFFLUENT NITRATE= 21.2 mgNO3-N/l
AEROBIC NITRATE= 21.2 mgNO3-N/l
ANOXIC NITRATE= 4.2 mgNO3-N/l
MLVSS= 1841 mgVSS/l
MEASURED OUR= 33 mgO/l/h
NITROGEN BALANCE:
NITTRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 533.14804 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1525 mgO/d
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 92.05 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE= 889 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 870.19804 mgN/d
NITROGEN BALANCE= 97.9 %

NITRATE PRODUCED FROM TKN = INF TKN - EFF TKN - TKN WASTED
352.2506 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 353 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 353 *4.57 = 1615 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 2376 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 761 mgO/d

COD INPUT TO SYSTEM = 5050 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION =
COD BALANCE = 85.1 %

APPENDIX B

MASS BALANCE ON CONTROL SYSTEM FOR STEADY STATE PERIOD 10 (DAYS 221-232)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 37 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.88 LITRE/DAY

OBSERVED PARAMETERS. fcv= 1.48
fn= 0.1

INFLUENT COD= 472 mgCOD/l
INFLUENT TKN= 44.1 mgN/l
INF. NITRATE= 441 mgN/d
EFFLUENT COD= 46 mgCOD/l
EFFLUENT TKN= 4.5 mgN/l
EFFLUENT NITRATE= 27.2 mgNO3-N/l
AEROBIC NITRATE= 27.2 mgNO3-N/l
ANOXIC NITRATE= 21.8 mgNO3-N/l
MLVSS= 1572 mgVSS/l
MEASURED OUR= 31 mgO/l/h
NITROGEN BALANCE:
NITTRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 458.1948 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1310 mgO/d
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 78.6 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE= 882 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 853.7948 mgN/d
NITROGEN BALANCE= 96.8 %

NITRATE PRODUCED FROM TKN = INF TKN - EFF TKN - TKN WASTED
313.44 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 313 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 313 *4.57 = 1431 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 2232 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 801 mgO/d

COD INPUT TO SYSTEM = 4720 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION =
COD BALANCE = 80 %

APPENDIX B

MASS BALANCE ON CONTROL SYSTEM FOR STEADY STATE PERIOD 11 (DAYS 233-240)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 37 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.9 LITRE/DAY

OBSERVED PARAMETERS. fcv= 1.48
fn= 0.1

INFLUENT COD= 457 mgCOD/l
INFLUENT TKN= 41.5 mgN/l
INF. NITRATE= 451 mgN/d
EFFLUENT COD= 47 mgCOD/l
EFFLUENT TKN= 5.2 mgN/l
EFFLUENT NITRATE= 26.6 mgNO3-N/l
AEROBIC NITRATE= 26.6 mgNO3-N/l
ANOXIC NITRATE= 21.7 mgNO3-N/l
MLVSS= 1457 mgVSS/l
MEASURED OUR= 32 mgO/l/h
NITROGEN BALANCE:
NITTRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 446.1017 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1276 mgO/d
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 72.85 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE= 866 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 836.9517 mgN/d
NITROGEN BALANCE= 96.6 %

NITRATE PRODUCED FROM TKN = INF TKN - EFF TKN - TKN WASTED
285.47 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 285 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 285 *4.57 = 1303 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 2304 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 1001 mgO/d

COD INPUT TO SYSTEM = 4570 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION =
COD BALANCE = 84.6 %

APPENDIX B

MASS BALANCE ON CONTROL SYSTEM FOR STEADY STATE PERIOD 12 (DAYS 247-262)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 37 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.96 LITRE/DAY

OBSERVED PARAMETERS. fcv= 1.48
fn= 0.1

INFLUENT COD= 490 mgCOD/l
INFLUENT TKN= 39.8 mgN/l
INF. NITRATE= 480 mgN/d
EFFLUENT COD= 46 mgCOD/l
EFFLUENT TKN= 3.3 mgN/l
EFFLUENT NITRATE= 23.9 mgNO3-N/l
AEROBIC NITRATE= 23.9 mgNO3-N/l
ANOXIC NITRATE= 19 mgNO3-N/l
MLVSS= 1630 mgVSS/l
MEASURED OUR= 25 mgO/l/h
NITROGEN BALANCE:
NITTRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 502.29184 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1437 mgO/d
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 81.5 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE= 878 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 855.79184 mgN/d
NITROGEN BALANCE= 97.5 '%

NITRATE PRODUCED FROM TKN = INF TKN - EFF TKN - TKN WASTED
280.332 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 284 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 284 *4.57 = 1299 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 1800 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 501 mgO/d

COD INPUT TO SYSTEM = 4900 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION =
COD BALANCE = 74.4 '%

APPENDIX B

MASS BALANCE ON CONTROL SYSTEM FOR STEADY STATE PERIOD 13 (DAYS 275-284)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.98 LITRE/DAY

OBSERVED PARAMETERS. fcv= 1.48
fn= 0.1

INFLUENT COD= 521 mgCOD/l
INFLUENT TKN= 37.8 mgN/l
INF. NITRATE= 490 mgN/d
EFFLUENT COD= 42 mgCOD/l
EFFLUENT TKN= 3.8 mgN/l
EFFLUENT NITRATE= 22.3 mgNO3-N/l
AEROBIC NITRATE= 22.3 mgNO3-N/l
ANOXIC NITRATE= 11.1 mgNO3-N/l
MLVSS= 2006 mgVSS/l
MEASURED OUR= 25 mgO/l/h
NITROGEN BALANCE:
NITTRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 480.70944 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1375 mgO/d
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 100.3 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE= 868 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 842.00944 mgN/d
NITROGEN BALANCE= 97 %

NITRATE PRODUCED FROM TKN = INF TKN - EFF TKN - TKN WASTED
235.976 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 236 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 236 *4.57 = 1077 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 1800 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 723 mgO/d

COD INPUT TO SYSTEM = 5210 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION =
COD BALANCE = 77.6 %

APPENDIX B

MASS BALANCE ON CONTROL SYSTEM FOR STEADY STATE PERIOD 14 (DAYS 285-296)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.95 LITRE/DAY

OBSERVED PARAMETERS. fcv= 1.48
fn= 0.1

INFLUENT COD= 464 mgCOD/l
INFLUENT TKN= 40.2 mgN/l
INF. NITRATE= 474 mgN/d
EFFLUENT COD= 39 mgCOD/l
EFFLUENT TKN= 4.9 mgN/l
EFFLUENT NITRATE= 26.2 mgNO3-N/l
AEROBIC NITRATE= 26.2 mgNO3-N/l
ANOXIC NITRATE= 14.4 mgNO3-N/l
MLVSS= 2036 mgVSS/l
MEASURED OUR= 23 mgO/l/h
NITROGEN BALANCE:
NITTRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 434.21525 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1242 mgO/d
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 101.8 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE= 876 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 847.01525 mgN/d
NITROGEN BALANCE= 96.7 %

NITRATE PRODUCED FROM TKN = INF TKN - EFF TKN - TKN WASTED
246.545 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 247 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 247 *4.57 = 1129 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 1656 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 527 mgO/d

COD INPUT TO SYSTEM = 4640 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION =
COD BALANCE = 79.8 %

APPENDIX B

MASS BALANCE ON CONTROL SYSTEM FOR STEADY STATE PERIOD 15 (DAYS 297-305)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.73 LITRE/DAY

OBSERVED PARAMETERS. fcv= 1.48
fn= 0.1

INFLUENT COD= 479 mgCOD/l
INFLUENT TKN= 50.1 mgN/l
INF. NITRATE= 366 mgN/d
EFFLUENT COD= 47 mgCOD/l
EFFLUENT TKN= 3.8 mgN/l
EFFLUENT NITRATE= 24.3 mgNO3-N/l
AEROBIC NITRATE= 24.3 mgNO3-N/l
ANOXIC NITRATE= 6.7 mgNO3-N/l
MLVSS= 1880 mgVSS/l
MEASURED OUR= 28 mgO/l/h
NITROGEN BALANCE:
NITTRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 471.1455 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1347 mgO/d
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 94 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE= 867 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 846.1455 mgN/d
NITROGEN BALANCE= 97.6 %

NITRATE PRODUCED FROM TKN = INF TKN - EFF TKN - TKN WASTED
366.226 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 366 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 366 *4.57 = 1672 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 2016 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 344 mgO/d

COD INPUT TO SYSTEM = 4790 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION =
COD BALANCE = 74.9 %

APPENDIX B

MASS BALANCE ON EXPERIMENTAL SYSTEM FOR STEADY STATE PERIOD 1 (DAYS 59-73)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 1 LITRE/DAY
VOLUME OF ALUM SLUDGE ADDED DAILY = 100 ml/d
OBSERVED PARAMETERS. fcv= 1.34
fn= 0.095

INFLUENT COD= 564 mgCOD/l
ALUM SLUDGE COD = 3530 mgCOD/l
INFLUENT TKN= 54 mgN/l
ALUM SLUDGE TKN = 11.2 mgN/l
INF. NITRATE= 500 mgN/d
EFFLUENT COD= 72 mgCOD/l
EFFLUENT TKN= 4 mgN/l
EFFLUENT NITRATE= 27 mgNO3-N/l
AEROBIC NITRATE= 27 mgNO3-N/l
ANOXIC NITRATE= 8.1 mgNO3-N/l
MLVSS= 2234 mgVSS/l
MEASURED OUR= 34 mgO/l/h
NITROGEN BALANCE:
NITRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 599.1 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1713 mgO/l
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 106.115 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE +
ALUM TKN = 1041 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 1018.275 mgN/d
NITROGEN BALANCE= 97.8 %

NITRATE PRODUCED FROM TKN = INF TKN + ALUM TKN - EFF TKN - TKN WASTED
390.605 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 395.1 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 395.1 *4.57 = 1806 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 2448 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 642.4 mgO/d

COD INPUT TO SYSTEM = 5993 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION = 4652 mgO/d
COD BALANCE = 77.6 %

APPENDIX B

MASS BALANCE ON EXPERIMENTAL SYSTEM FOR STEADY STATE PERIOD 2 (DAYS 74-86)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.85 LITRE/DAY
VOLUME OF ALUM SLUDGE ADDED DAILY = 100 ml/d
OBSERVED PARAMETERS. fcv= 1.4
fn= 0.087

INFLUENT COD= 520 mgCOD/l
ALUM SLUDGE COD = 3530 mgCOD/l
INFLUENT TKN= 37 mgN/l
ALUM SLUDGE TKN = 11.2 mgN/l
INF. NITRATE= 423 mgN/d
EFFLUENT COD= 80 mgCOD/l
EFFLUENT TKN= 4 mgN/l
EFFLUENT NITRATE= 12 mgNO3-N/l
AEROBIC NITRATE= 12 mgNO3-N/l
ANOXIC NITRATE= 0.8 mgNO3-N/l
MLVSS= 2241 mgVSS/l
MEASURED OUR= 27 mgO/l/h
NITROGEN BALANCE:
NITRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 525.69782 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1503 mgO/l
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 97.4835 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE +
ALUM TKN = 794.1 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 784.78132 mgN/d
NITROGEN BALANCE= 98.8 '%

NITRATE PRODUCED FROM TKN = INF TKN + ALUM TKN - EFF TKN - TKN WASTED
229.8525 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 232.8 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 232.8 *4.57 = 1064 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 1944 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 879.9 mgO/d

COD INPUT TO SYSTEM = 5553 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION = 4828 mgO/d
COD BALANCE = 86.9 '%

MASS BALANCE ON EXPERIMENTAL SYSTEM FOR STEADY STATE PERIOD 3 (DAYS 87-106)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.95 LITRE/DAY
VOLUME OF ALUM SLUDGE ADDED DAILY = 50 ml/d
OBSERVED PARAMETERS. fcv= 1.32
fn= 0.083

INFLUENT COD= 538 mgCOD/l
ALUM SLUDGE COD = 4389 mgCOD/l
INFLUENT TKN= 49.8 mgN/l
ALUM SLUDGE TKN = 47.3 mgN/l
INF. NITRATE= 473 mgN/d
EFFLUENT COD= 91 mgCOD/l
EFFLUENT TKN= 3.1 mgN/l
EFFLUENT NITRATE= 22.7 mgNO3-N/l
AEROBIC NITRATE= 22.7 mgNO3-N/l
ANOXIC NITRATE= 4.8 mgNO3-N/l
MLVSS= 2137 mgVSS/l
MEASURED OUR= 29 mgO/l/h
NITROGEN BALANCE:
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 600.29704 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1717 mgO/l
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 88.6855 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE +
ALUM TKN = 973.4 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 948.27254 mgN/d
NITROGEN BALANCE= 97.4 %

NITRATE PRODUCED FROM TKN = INF TKN + ALUM TKN - EFF TKN - TKN WASTED
377.5919 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 375.8 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 375.8 *4.57 = 1717 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 2088 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 370.7 mgO/d

COD INPUT TO SYSTEM = 5599.45 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION = 4499 mgO/d
COD BALANCE = 80.3 %

MASS BALANCE ON EXPERIMENTAL SYSTEM FOR STEADY STATE PERIOD 4 (DAYS 107-121)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.96 LITRE/DAY
VOLUME OF ALUM SLUDGE ADDED DAILY = 50 ml/d
OBSERVED PARAMETERS. fcv= 1.35
fn= 0.082

INFLUENT COD= 530 mgCOD/l
ALUM SLUDGE COD = 4389 mgCOD/l
INFLUENT TKN= 57.1 mgN/l
ALUM SLUDGE TKN = 47.3 mgN/l
INF. NITRATE= 481 mgN/d
EFFLUENT COD= 58 mgCOD/l
EFFLUENT TKN= 3.2 mgN/l
EFFLUENT NITRATE= 31.7 mgNO3-N/l
AEROBIC NITRATE= 31.7 mgNO3-N/l
ANOXIC NITRATE= 10.7 mgNO3-N/l
MLVSS= 2336 mgVSS/l
MEASURED OUR= 34 mgO/l/h
NITROGEN BALANCE:
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 573.7066 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1641 mgO/l
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 95.776 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE +
ALUM TKN = 1054 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 1020.2276 mgN/d
NITROGEN BALANCE= 96.8 %

NITRATE PRODUCED FROM TKN = INF TKN + ALUM TKN - EFF TKN - TKN WASTED
442.3506 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 440.2 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 440.2 *4.57 = 2012 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 2448 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 436.3 mgO/d

COD INPUT TO SYSTEM = 5519.45 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION = 4293 mgO/d
COD BALANCE = 77.8 %

MASS BALANCE ON EXPERIMENTAL SYSTEM FOR STEADY STATE PERIOD 5 (DAYS 122-137)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.83 LITRE/DAY
VOLUME OF ALUM SLUDGE ADDED DAILY = 50 ml/d
OBSERVED PARAMETERS. fcv= 1.36
fn= 0.085

INFLUENT COD= 468 mgCOD/l
ALUM SLUDGE COD = 4389 mgCOD/l
INFLUENT TKN= 53.7 mgN/l
ALUM SLUDGE TKN = 47.3 mgN/l
INF. NITRATE= 414 mgN/d
EFFLUENT COD= 70 mgCOD/l
EFFLUENT TKN= 4.1 mgN/l
EFFLUENT NITRATE= 26 mgNO3-N/l
AEROBIC NITRATE= 26 mgNO3-N/l
ANOXIC NITRATE= 7.1 mgNO3-N/l
MLVSS= 2364 mgVSS/l
MEASURED OUR= 29 mgO/l/h
NITROGEN BALANCE:
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 526.95432 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1507 mgO/l
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 100.47 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE +
ALUM TKN = 953.4 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 929.92932 mgN/d
NITROGEN BALANCE= 97.5 '%

NITRATE PRODUCED FROM TKN = INF TKN + ALUM TKN - EFF TKN - TKN WASTED
394.2952 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 394.5 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 394.5 *4.57 = 1803 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 2088 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 285.2 mgO/d

COD INPUT TO SYSTEM = 4899.45 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION = 4161 mgO/d
COD BALANCE = 84.9 '%

APPENDIX B

MASS BALANCE ON EXPERIMENTAL SYSTEM FOR STEADY STATE PERIOD 6 (DAYS 138-157)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.74 LITRE/DAY
VOLUME OF ALUM SLUDGE ADDED DAILY = 50 ml/d
OBSERVED PARAMETERS. fcv= 1.38
fn= 0.084

INFLUENT COD= 507 mgCOD/l
ALUM SLUDGE COD = 4389 mgCOD/l
INFLUENT TKN= 45 mgN/l
ALUM SLUDGE TKN = 47.3 mgN/l
INF. NITRATE= 370 mgN/d
EFFLUENT COD= 60 mgCOD/l
EFFLUENT TKN= 3.2 mgN/l
EFFLUENT NITRATE= 15.8 mgNO3-N/l
AEROBIC NITRATE= 15.8 mgNO3-N/l
ANOXIC NITRATE= 0.2 mgNO3-N/l
MLVSS= 2131 mgVSS/l
MEASURED OUR= 29 mgO/l/h
NITROGEN BALANCE:
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 523.852 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1498 mgO/l
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 89.502 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE +
ALUM TKN = 822.4 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 804.304 mgN/d
NITROGEN BALANCE= 97.8 %

NITRATE PRODUCED FROM TKN = INF TKN + ALUM TKN - EFF TKN - TKN WASTED
328.335 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 323.5 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 323.5 *4.57 = 1479 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 2088 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 609.4 mgO/d

COD INPUT TO SYSTEM = 5289.45 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION = 4225
COD BALANCE = 79.9 %

APPENDIX B

MASS BALANCE ON EXPERIMENTAL SYSTEM FOR STEADY STATE PERIOD 7 (DAYS 158-177)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.76 LITRE/DAY
VOLUME OF ALUM SLUDGE ADDED DAILY = 50 ml/d
OBSERVED PARAMETERS. fcv= 1.35
fn= 0.083

INFLUENT COD= 519 mgCOD/l
ALUM SLUDGE COD = 4389 mgCOD/l
INFLUENT TKN= 57 mgN/l
ALUM SLUDGE TKN = 47.3 mgN/l
INF. NITRATE= 376 mgN/d
EFFLUENT COD= 55 mgCOD/l
EFFLUENT TKN= 3.8 mgN/l
EFFLUENT NITRATE= 22.5 mgNO3-N/l
AEROBIC NITRATE= 22.5 mgNO3-N/l
ANOXIC NITRATE= 1.3 mgNO3-N/l
MLVSS= 2385 mgVSS/l
MEASURED OUR= 30.2 mgO/l/h
NITROGEN BALANCE:
NITRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 573.38787 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1640 mgO/l
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 98.9775 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE +
ALUM TKN = 948.4 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 936.68037 mgN/d
NITROGEN BALANCE= 95.3 %

NITRATE PRODUCED FROM TKN = INF TKN + ALUM TKN - EFF TKN - TKN WASTED
432.3057 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 439.5 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 439.5 *4.57 = 2009 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 2174 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 165.8 mgO/d

COD INPUT TO SYSTEM = 5409.45 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION = 4010
COD BALANCE = 75.2 %

APPENDIX B

MASS BALANCE ON EXPERIMENTAL SYSTEM FOR STEADY STATE PERIOD 8 (DAYS 178-193)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.71 LITRE/DAY
VOLUME OF ALUM SLUDGE ADDED DAILY = 100 ml/d
OBSERVED PARAMETERS. fcv= 1.35
fn= 0.081

INFLUENT COD= 497 mgCOD/l
ALUM SLUDGE COD = 4389 mgCOD/l
INFLUENT TKN= 45.9 mgN/l
ALUM SLUDGE TKN = 47.3 mgN/l
INF. NITRATE= 354 mgN/d
EFFLUENT COD= 66 mgCOD/l
EFFLUENT TKN= 3.6 mgN/l
EFFLUENT NITRATE= 20.8 mgNO3-N/l
AEROBIC NITRATE= 20.8 mgNO3-N/l
ANOXIC NITRATE= 4.9 mgNO3-N/l
MLVSS= 2321 mgVSS/l
MEASURED OUR= 30 mgO/l/h
NITROGEN BALANCE:
NITRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 460.94496 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1318 mgO/l
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 94.0005 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATES +
ALUM TKN = 817.7 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATES DENITRIFIED=
= 801.38546 mgN/d
NITROGEN BALANCE= 98 %

NITRATE PRODUCED FROM TKN = INF TKN + ALUM TKN - EFF TKN - TKN WASTED
330.8207 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 329.7 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 329.7 *4.57 = 1507 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 2160 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 653.4 mgO/d

COD INPUT TO SYSTEM = 5408.9 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION = 4252
COD BALANCE = 78.6 %

APPENDIX B

MASS BALANCE ON EXPERIMENTAL SYSTEM FOR STEADY STATE PERIOD 9 (DAYS 194-220)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.69 LITRE/DAY
VOLUME OF ALUM SLUDGE ADDED DAILY = 100 ml/d
OBSERVED PARAMETERS. fcv= 1.31
fn= 0.08

INFLUENT COD= 505 mgCOD/l
ALUM SLUDGE COD = 4389 mgCOD/l
INFLUENT TKN= 48 mgN/l
ALUM SLUDGE TKN = 47.3 mgN/l
INF. NITRATE= 343 mgN/d
EFFLUENT COD= 72 mgCOD/l
EFFLUENT TKN= 3.7 mgN/l
EFFLUENT NITRATE= 18.4 mgNO3-N/l
AEROBIC NITRATE= 18.4 mgNO3-N/l
ANOXIC NITRATE= 1.8 mgNO3-N/l
MLVSS= 2452 mgVSS/l
MEASURED OUR= 36 mgO/l/h
NITROGEN BALANCE:
NITRATE DENITRIFIED= NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 490.59264 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1403 mgO/l
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 94.402 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE +
ALUM TKN = 828 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 808.20464 mgN/d
NITROGEN BALANCE= 100 %

NITRATE PRODUCED FROM TKN = INF TKN + ALUM TKN - EFF TKN - TKN WASTED
350.4198 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 344 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 344 *4.57 = 1573 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 2592 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 1019 mgO/d

COD INPUT TO SYSTEM = 5488.9 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION = 4805
COD BALANCE = 86.9 %

APPENDIX B

MASS BALANCE ON EXPERIMENTAL SYSTEM FOR STEADY STATE PERIOD 10 (DAYS 221-232)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.85 LITRE/DAY
VOLUME OF ALUM SLUDGE ADDED DAILY = 100 ml/d
OBSERVED PARAMETERS. fcv= 1.27
fn= 0.07

INFLUENT COD= 472 mgCOD/l
ALUM SLUDGE COD = 4389 mgCOD/l
INFLUENT TKN= 44.1 mgN/l
ALUM SLUDGE TKN = 47.3 mgN/l
INF. NITRATE= 424 mgN/d
EFFLUENT COD= 62 mgCOD/l
EFFLUENT TKN= 5 mgN/l
EFFLUENT NITRATE= 19.7 mgNO3-N/l
AEROBIC NITRATE= 19.7 mgNO3-N/l
ANOXIC NITRATE= 5.1 mgNO3-N/l
MLVSS= 2482 mgVSS/l
MEASURED OUR= 36 mgO/l/h
NITROGEN BALANCE:
NITRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 513.84128 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1470 mgO/l
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 83.147 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE +
ALUM TKN = 870 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 846.45828 mgN/d
NITROGEN BALANCE= 99.6 %

NITRATE PRODUCED FROM TKN = INF TKN + ALUM TKN - EFF TKN - TKN WASTED
307.843 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 304 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 304 *4.57 = 1387 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 2592 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 1205 mgO/d

COD INPUT TO SYSTEM = 5158.9 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION = 4929
COD BALANCE = 94.9 %

APPENDIX B

MASS BALANCE ON EXPERIMENTAL SYSTEM FOR STEADY STATE PERIOD 11 (DAYS 233-240)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.84 LITRE/DAY
VOLUME OF ALUM SLUDGE ADDED DAILY = 300 ml/d
OBSERVED PARAMETERS. fcv= 1.28
fn= 0.07

INFLUENT COD= 457 mgCOD/l
ALUM SLUDGE COD = 1943 mgCOD/l
INFLUENT TKN= 41.5 mgN/l
ALUM SLUDGE TKN = 25.3 mgN/l
INF. NITRATE= 421 mgN/d
EFFLUENT COD= 77 mgCOD/l
EFFLUENT TKN= 6.8 mgN/l
EFFLUENT NITRATE= 19.3 mgNO3-N/l
AEROBIC NITRATE= 19.3 mgNO3-N/l
ANOXIC NITRATE= 5.8 mgNO3-N/l
MLVSS= 2432 mgVSS/l
MEASURED OUR= 31 mgO/l/h
NITROGEN BALANCE:
NITRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 493.74166 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1412 mgO/l
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 79.04 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE +
ALUM TKN = 844 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 841.61166 mgN/d
NITROGEN BALANCE= 98.7 %

NITRATE PRODUCED FROM TKN = INF TKN + ALUM TKN - EFF TKN - TKN WASTED
267.7844 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 282 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 282 *4.57 = 1289 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 2232 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 943 mgO/d

COD INPUT TO SYSTEM = 5152.9 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION = 4770
COD BALANCE = 92.6 %

APPENDIX B

MASS BALANCE ON EXPERIMENTAL SYSTEM FOR STEADY STATE PERIOD 12 (DAYS 247-262)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 0 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.94 LITRE/DAY
VOLUME OF ALUM SLUDGE ADDED DAILY = 300 ml/d
OBSERVED PARAMETERS. fcv= 1.35
fn= 0.07

INFLUENT COD= 490 mgCOD/l
ALUM SLUDGE COD = 1943 mgCOD/l
INFLUENT TKN= 39.8 mgN/l
ALUM SLUDGE TKN = 25.3 mgN/l
INF. NITRATE= 471 mgN/d
EFFLUENT COD= 75 mgCOD/l
EFFLUENT TKN= 3.8 mgN/l
EFFLUENT NITRATE= 20.4 mgNO3-N/l
AEROBIC NITRATE= 20.4 mgNO3-N/l
ANOXIC NITRATE= 7.4 mgNO3-N/l
MLVSS= 2412 mgVSS/l
MEASURED OUR= 25.2 mgO/l/h
NITROGEN BALANCE:
NITRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 520.44804 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1488 mgO/l
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 83.214 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE +
ALUM TKN = 877 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 852.92204 mgN/d
NITROGEN BALANCE= 98 %

NITRATE PRODUCED FROM TKN = INF TKN + ALUM TKN - EFF TKN - TKN WASTED
279.6564 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 273 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 273 *4.57 = 1246 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 1814 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 568 mgO/d

COD INPUT TO SYSTEM = 5480.9 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION = 4528
COD BALANCE = 82.6 %

APPENDIX B

MASS BALANCE ON EXPERIMENTAL SYSTEM FOR STEADY STATE PERIOD 13 (DAYS 275-284)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 40 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.95 LITRE/DAY
VOLUME OF ALUM SLUDGE ADDED DAILY = 300 ml/d
OBSERVED PARAMETERS. fcv= 1.44
fn= 0.1

INFLUENT COD= 521 mgCOD/l
ALUM SLUDGE COD = 1795 mgCOD/l
INFLUENT TKN= 37.8 mgN/l
ALUM SLUDGE TKN = 14.8 mgN/l
INF. NITRATE= 473 mgN/d
EFFLUENT COD= 89 mgCOD/l
EFFLUENT TKN= 4.3 mgN/l
EFFLUENT NITRATE= 12.9 mgNO3-N/l
AEROBIC NITRATE= 12.9 mgNO3-N/l
ANOXIC NITRATE= 9.1 mgNO3-N/l
MLVSS= 2303 mgVSS/l
MEASURED OUR= 24.8 mgO/l/h
NITROGEN BALANCE:
NITRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 560.64883 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1603 mgO/l
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 109.3925 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE +
ALUM TKN = 855 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 847.20133 mgN/d
NITROGEN BALANCE= 99 %

NITRATE PRODUCED FROM TKN = INF TKN + ALUM TKN - EFF TKN - TKN WASTED
224.6897 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 229 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 229 *4.57 = 1046 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 1786 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 740 mgO/d

COD INPUT TO SYSTEM = 5746.5 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION = 5002
COD BALANCE = 87 %

APPENDIX B

MASS BALANCE ON EXPERIMENTAL SYSTEM FOR STEADY STATE PERIOD 14 (DAYS 285-296)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 40 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.92 LITRE/DAY
VOLUME OF ALUM SLUDGE ADDED DAILY = 650 ml/d
OBSERVED PARAMETERS. fcv= 1.39
fn= 0.08

INFLUENT COD= 464 mgCOD/l
ALUM SLUDGE COD = 1795 mgCOD/l
INFLUENT TKN= 40.2 mgN/l
ALUM SLUDGE TKN = 14:8 mgN/l
INF. NITRATE= 458 mgN/d
EFFLUENT COD= 90 mgCOD/l
EFFLUENT TKN= 5.5 mgN/l
EFFLUENT NITRATE= 21.2 mgNO3-N/l
AEROBIC NITRATE= 21.2 mgNO3-N/l
ANOXIC NITRATE= 17.4 mgNO3-N/l
MLVSS= 2566 mgVSS/l
MEASURED OUR= 23.1 mgO/l/h
NITROGEN BALANCE:
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 457.75702 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1309 mgO/l
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 103.923 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE +
ALUM TKN = 870 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 846.03502 mgN/d
NITROGEN BALANCE= 98.7 '%

NITRATE PRODUCED FROM TKN = INF TKN + ALUM TKN - EFF TKN - TKN WASTED
244.084 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 231 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 231 *4.57 = 1056 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 1663 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 607 mgO/d

COD INPUT TO SYSTEM = 5808.75 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION = 4740
COD BALANCE = 81.6 '%

APPENDIX B

MASS BALANCE ON EXPERIMENTAL SYSTEM FOR STEADY STATE PERIOD 15 (DAYS 297-305)

PROCESS CONFIGURATION:
SLUDGE AGE Rs= 20 DAYS
AEROBIC VOLUME= 3 LITRES
ANOXIC VOLUME= 7 LITRES
A RECYCLE= 40 LITRES/DAY
S RECYCLE= 10 LITRES/DAY
INFLUENT FLOW= 10 LITRES/DAY
ADDITIONAL FLOW THROUGH SYSTEM CAUSED BY NITRATE ADDITION= 0.72 LITRE/DAY
VOLUME OF ALUM SLUDGE ADDED DAILY = 650 ml/d
OBSERVED PARAMETERS. fcv= 1.34
fn= 0.07

INFLUENT COD= 479 mgCOD/l
ALUM SLUDGE COD = 1795 mgCOD/l
INFLUENT TKN= 50.1 mgN/l
ALUM SLUDGE TKN = 14.8 mgN/l
INF. NITRATE= 361 mgN/d
EFFLUENT COD= 70 mgCOD/l
EFFLUENT TKN= 9.6 mgN/l
EFFLUENT NITRATE= 11.8 mgNO3-N/l
AEROBIC NITRATE= 11.8 mgNO3-N/l
ANOXIC NITRATE= 6.9 mgNO3-N/l
MLVSS= 2729 mgVSS/l
MEASURED OUR= 27.3 mgO/l/h
NITROGEN BALANCE:
NITRATE DENITRIFIED = NITRATE BALANCE ON ANOXIC REACTOR
NITRATE DENITRIFIED = INFLUENT NITRATE + NITRATE RECYCLED - NITRATE LEAVING ANOXIC REACTOR.
= 531.289536 mgNO3-N/d
OXYGEN RECOVERED IN DENITRIFICATION = 2.86 * NITRATE DENITRIFIED= 1519 mgO/l
NITROGEN WASTED IN SLUDGE DAILY = fn*VSS WASTED DAILY= 98.244 mgN/d

NITROGEN INPUT TO SYSTEM = INF TKN + INF NITRATE +
ALUM TKN = 872 mgN/d
NITROGEN LEAVING SYSTEM= EFF TKN + EFF NO3 + N WASTED + NITRATE DENITRIFIED=
= 857.443536 mgN/d
NITROGEN BALANCE= 98.4 '%

NITRATE PRODUCED FROM TKN = INF TKN + ALUM TKN - EFF TKN - TKN WASTED
303.2048 mgNO3-N/d
NITRATE PRODUCED IN SYSTEM FROM NITRATE BALANCE=
EFF NO3 + NO3 DENITRIFIED - INF NO3= 297 mgNO3-N/d

OXYGEN DEMAND FOR NITRIFICATION= 297 *4.57 = 1356 mgO/d
COD BALANCE:

TOTAL MEASURED OXYGEN DEMAND = 1966 mgO/d
OXYGEN DEMAND FOR COD REMOVAL = 609 mgO/d

COD INPUT TO SYSTEM = 5956.75 mgCOD/d
COD LEAVING SYSTEM =EFF COD + COD WASTED + OXYGEN DEMAND + OXYGEN RECOVERED FROM DENITRIFICATION = 4753
COD BALANCE = 79.8 '%

APPENDIX C:
DATA FROM LABORATORY SYSTEMS

APPENDIX C: DATA MEASURED IN CONTROL SYSTEM

DATE / STEADY STATE PERIOD No	DAY No.	MEASURED INFLUENT CONCENTRATIONS			MEASURED EFFLUENT CONCENTRATIONS				MASS IN EFFLUENT AFTER DILUTION				MLSS	MLVSS	DSVI	N ADDED	ANOX NO3	OUR	COD SLUDGE	pH
		COD mg/l	TKN mgN/l	PHOS mg/l	COD mg/l	TKN mgN/l	PHOS mg/l	NO3 mg/l	COD mg	TKN mgN	PHOS mg	NO3 mg	mg/l	mg/l	ml/g	mg	mg/l	mgO/ 17d	mg/l	
15 1 INF.																				
24-Jan-89	1	589	61.6		100	32.9		16.4	1494	494		246								
25-Jan-89	2	591			73			15.4	1098			231	2148	1840	186					
26-Jan-89	3	585			73			19.4	1095			291	1966	1718	186					7.5
27-Jan-89	4	585	52.9		102	11.7		10.2	1530	176		153	2168	1702	184					7.6
28-Jan-89	5	412	49.6		63	13.4		6.4	945	201		96	2664	2298	175					
29-Jan-89	6																			
30-Jan-89	7	559	67.5		69	26.0		2.4	1035	390		36	3050	2566	153					7.7
31-Jan-89	8	563	55.0		69	23.0		6.6	1041	345		99	2882	2426	185					7.7
01-Feb-89	9	518	46.2		65	16.0		7.4	980	240		111	3084	2658	205					7.7
02-Feb-89	10	486	40.6		59	11.6		8.4	888	174		126	3004		179					7.6
03-Feb-89	11	333	40.6		48	5.7		9.6	726	86		144	3276	2686						7.4
04-Feb-89	12	483	40.0		52	1.1		9.6	786	17		144	3022	2686	188					
05-Feb-89	13							10.4				156								
06-Feb-89	14	510	50.0		63	4.3		10.5	938	65		158	3248	2706	180					7.4
07-Feb-89	15	488	42.6	24.8	44	3.9	13.7	10.5	666	59	206	157	3446	2790	169					7.5
08-Feb-89	16														184					7.6
09-Feb-89	17	399	41.3	26.3	38	3.2	17.9	11.7	575	48	269	175	3390	2768	187					7.7
ADD NO3																				
10-Feb-89	18	425	45.6	26.9	38	4.3	15.2	12.2	575	65	228	183	3556	2884	178					7.6
11-Feb-89	19	479	42.0	25.2	41	3.8	13.4	23.4	609	57	201	351	3356	2736	188					7.5
12-Feb-89	20																			
13-Feb-89	21	349	46.6	24.4	37	2.7	21.6	20.0	549	41	324	300	3422	2812	195					7.6
14-Feb-89	22	463	48.3	22.8	49	4.3	22.6	13.2	732	65	339	198	3330	2700	210		0.8			
15-Feb-89	23	480	52.1	26.4	43	8.5	22.6	15.8	641	128	339	237	3568	2866	215					7.5
16-Feb-89	24	478	49.1	26.0	41	3.2	23.2	16.2	609	48	348	243	3464	2836	240					7.6
17-Feb-89	25				41		23.2	16.6	629		360	257	3332	2768	230	250	0.8			
18-Feb-89	26			23.2			22.0	8.4			341	130	3002		244	250				
19-Feb-89	27															250				
20-Feb-89	28	463	38.9	23.3	28	3.5	19.3	7.0	426	53	290	105	3250	2686	246		0.2			
21-Feb-89	29	488	40.3	24.4	53	3.4	20.1		822	53	312		3492	2870	178	250				
22-Feb-89	30			23.8			21.3	7.2			320	108								
10 1 INF.																				
23-Feb-89	31	522	44.0	32.1	40	2.0	23.5	14.6	440	22	259	161	2444	2058	225	500	1.8			
24-Feb-89	32	611	45.8	33.2	69	4.2	24.1	18.4	759	46	265	202	2542	2138	243	500				8.1
25-Feb-89	33	514	44.4	33.2	41	2.8	26.1	19.4	439	30	283	210	2298	1868	261	425				7.8
26-Feb-89	34															475				
27-Feb-89	35	516	45.2	32.8	31	3.6	30.8	19.8	338	39	336	216	2726	2214	220	450	8.0			7.9
28-Feb-89	36	503	41.6	31.6	40	3.4	28.2	22.4	440	37	310	246	2480	2098	215	500				7.9
01-Mar-89	37	454	43.0	31.6	36	2.0	26.6	20.0	385	21	285	214	2414	2030	248	350	6.8			
02-Mar-89	38	507	42.0	34.6	42	3.0	27.0	19.8	462	33	297	218	2374	1930	232	500				7.7
03-Mar-89	39	514	45.0	31.2	52	3.0	24.0	22.0	571	33	262	240	2222	1888	248	450	11.0			7.8
04-Mar-89	40	505		33.0	19		26.8	21.6	206		293	237	2394	2010	216	475				7.7
05-Mar-89	41	520	44.0	32.8	21	0.6	26.3	16.6	231	7	289	183	2480	2090	222	500				7.8
06-Mar-89	42	528	46.5	33.7	17		25.2	13.0	181		272	140	2412	2108	228	400	4.6			7.7
07-Mar-89	43	533	38.9	32.8	30		26.3	14.0	329		287	153	2486		219	450				7.6
AVERAGE		519	43.7	32.7	36	2.7	26	18.5	398	30	286	202	2439	2039	231	460	6.4			7.8
08-Mar-89	44	505	55.4	33.7	32	3.9	24.3	17.6	354	43	267	194	2490	2106	220	500	8.2			7.6
09-Mar-89	45	535	57.7	32.8	62	5.2	26.0	20.9	677	56	282	227	2516	2106		425				7.7
10-Mar-89	46	533	58.0	24.3	32	5.7	22.3	20.9	351	62	243	228	2386	1986	230	450	12.8		2415	7.7
11-Mar-89	47	541	57.7	25.9	48	2.0	23.3	24.6	531	22	256	271	2350	1940	226	500				7.7
12-Mar-89	48	503	57.7	26.5	57	3.6	22.1	20.2	619	39	239	218	2818	2454	201	400				7.6
13-Mar-89	49	538	59.8	26.8		3.4	22.4	19.9		34	224	199	2228	1882						
14-Mar-89	50	506	59.2	25.9	74	4.0	20.1	21.4	811	44	221	235	2382	2036	216	500				7.4
15-Mar-89	51	502	58.1	25.3	12	2.8	18.9	20.4	129	30	203	219	2498	2128	206	375	2.9			
16-Mar-89	52	480	57.0	24.4	48	10.0	19.2	10.2	521	108	207	110	2466	2090	216	400				7.9
17-Mar-89	53	518	58.1	24.7	42	8.1	19.5	18.6	456	87	210	201	2568	2204	221	400	8.0			7.7
18-Mar-89	54		62.7	24.9		4.6	20.4	25.6		51	225	282	2474	2102	229	500				7.5
19-Mar-89	55	578	61.9	25.1	74	5.0	18.0	23.6	796	54	195	255	2394	1982	216	400				

APPENDIX C: DATA MEASURED IN CONTROL SYSTEM

DATE	DAY No.	MEASURED INFLUENT CONCENTRATIONS			MEASURED EFFLUENT CONCENTRATIONS				MASS IN EFFLUENT AFTER DILUTION				MLSS	MLVSS	DSVI	N ADDED	ANOX NO3	OUR mgO/ 17d	COD SLUDGE	pH
		COD mg/l	TKN mgN/l	PHOS mg/l	COD mg/l	TKN mgN/l	PHOS mg/l	NO3 mg/l	COD mg	TKN mgN	PHOS mg	NO3 mg	mg/l	mg/l	ml/g	mg	mg/l		mg/l	
20-Mar-89	56	566	61.9	24.8	56	3.8	19.7	23.0	601	41	211	246	2788	2384	165	350	5.8			7.3
21-Mar-89	57	529	59.1	24.5	49	3.8	19.7	23.8	528	41	213	257	2462	2074	203	400			3665	
22-Mar-89	58	550	59.9	24.0	69	3.4	19.7	24.4	754	37	215	266	2496	2116	200	450	7.2			
AVERAGE		527	58.9	26.2	51	4.6	21.0	21.0	549	50	229	228	2488	2106	211	432	7.5		3040	7.6
23-Mar-89	59	579	59.1	23.4	86	4.2	16.9	23.8	948	46	186	262	2124	1832	220	500				
24-Mar-89	60	616	56.6	24.0	37	3.6	19.2	23.8	399	39	207	257	2458	2086	210	400				
25-Mar-89	61	566	54.0	23.7	29	3.2	18.3	26.4	308	35	198	285	2372	1964	210	400				
26-Mar-89	62	533	54.6	23.1	24	2.5	18.3	29.0	269	28	202	319	2622	2194	204	500				
27-Mar-89	63	582	59.1	24.5	118	2.5	18.6	26.2	1281	27	202	284				425				
28-Mar-89	64	562	54.3	23.7	12	2.7	18.0	34.4	134	29	198	378	2178	1834	199	500				
29-Mar-89	65	619	54.6	23.5	73	4.6	19.2	25.0	784	49	206	268	2646	2290	189	350				7.4
30-Mar-89	66	529	51.0	23.8	73	3.9	18.7	17.4	792	42	201	188	2630	2246	190	400				7.5
31-Mar-89	67	542	51.0	22.9	78	3.2	18.9	17.8	858	35	208	196	2566	2208	201	500		34		
01-Apr-89	68	575	52.4	23.2	57	2.7	20.1	20.2	619	29	217	218	2792	2354	191	400				
02-Apr-89	69	591	50.7	21.8	45	2.7	18.9	19.2	488	29	204	207	2448	2112	204	400		37		7.5
03-Apr-89	70	532	50.1	23.5	52	4.3	16.4	18.4	566	47	177	199	2586	2248	213	400		36	3064	
04-Apr-89	71	564	57.4	24.3	52	3.6	18.1	21.8	577	40	199	240	2346	2030	213	500		32		
05-Apr-89	72	524		23.5	60		18.4	24.6	653		198	266	2286	1972	219	400	9.4	35		
06-Apr-89	73	552	52.9	25.5	52	2.7	17.5	22.2	577	29	192	244	2566	2132	208	500		27		7.4
AVERAGE 1		564	54.1	23.6	57	3.3	18.4	23.3	617	36	200	254	2473	2107	205	438		33	3064	7.4
07-Apr-89	74	504	38.1	23.3	36	2.9	18.0	20.0	392	32	195	216	2132	1864	219	400		23		
08-Apr-89	75	508	31.9	23.9	48	3.5	18.6	12.0	532	39	204	132	2302	1952	232	500				
09-Apr-89	76	544	38.9	25.5	53	3.5	19.4	13.0	586	39	214	143	2376	2142	224	500				
10-Apr-89	77	544	28.2		28	4.1	21.1	10.8	310	45	232	119	2220	1874	225	500		27		
11-Apr-89	78	523	38.4	24.1	122	4.8	21.1	12.6	1342	52	232	139	2320	2004	216	500		22	2991	
12-Apr-89	79	535	38.9	24.7	51	2.7	18.9	21.0	563	29	207	231	2152	1842	217	500	6.2	27		
13-Apr-89	80	508	33.6	20.2	43	2.1	18.9	17.6	476	23	207	194	2284	1962	212	500		21		
14-Apr-89	81	504	37.2	25.3	47	3.9	19.4	17.0	520	43	214	187	2104	1816	238	500		24		7.6
15-Apr-89	82	531	43.7	24.8	75	4.1	19.1	14.4	819	44	210	158	2040	1836	221	478				
16-Apr-89	83	578	38.4	25.3	41	3.6	18.5	10.8	451	40	204	119	2254	1904	200	500				7.6
17-Apr-89	84	434	35.6	24.5			20.6	10.0			224	109	2288	1982	204	425		27	2703	7.5
18-Apr-89	85	483	39.2	25.6	70	3.5	19.4	13.6	766	39	214	150	2072	1732	193	500		22		7.5
19-Apr-89	86	557	38.1	25.1	57	0.8	19.1	13.0	625	9	209	142	2472	2130	202	450	7.0	23	3441	
AVERAGE 2		520	36.9	24.4	56	3.3	19.4	14.3	614	36	213	157	2232	1926	216	481		24	3045	7.5
20-Apr-90	87	500	52.9	24.8	102	3.2	20.9	18.4	1122	35	230	202	1742	1514	201	500		27		7.5
21-Apr-89	88	573	53.8	24.0	70	2.9	16.2	19.8	762	32	177	217	1838	1532	200	475	12.0	27		
22-Apr-89	89	612	53.2	22.9	49	2.9	17.9	30.4	535	32	196	334				500			2352	
23-Apr-89	90			24.0			18.7	28.4			202	307	1888	1592	168	400		34		
24-Apr-89	91	544	56.3	24.0	49	2.2	19.8	25.8	531	24	216	281	1810	1568	184	450	6.0	38		8.1
25-Apr-89	92	553	52.6	23.2	42	4.6	19.0	27.6	458	51	209	304	1760	1510	170	500		30	2038	7.9
26-Apr-89	93	542	55.4			3.1		30.8		34		339	1918	1652	200	500		37		7.9
27-Apr-89	94	595	51.2	23.5	46	2.2	19.3	25.8	506	24	210	281	1836	1588	191	450		35	2225	7.7
28-Apr-89	95	553	56.0	24.6	66	3.8	19.3	18.8	718	41	211	206	1850	1588	198	475	9.0	30	2212	8.0
29-Apr-89	96	498		23.0	57		19.2	21.8	628		211	240				500				
30-Apr-89	97	549	41.0	24.4	41	2.8	18.9		442	30	204					400				
01-May-89	98	528	55.7	24.1	37	2.4	20.6	17.8	398	26	223	192	1942	1660	171	400	4.6	30		7.7
02-May-89	99	557	54.3	23.3	49	2.2	19.7	17.2	541	25	217	189	2222	2012	180	500		34		
03-May-89	100	512	46.8	25.0	66	0.3	20.0	15.4	711	3	217	167	2056	1730	186	425		30	2703	
04-May-89	101	508	44.0	23.3	54	0.0	19.7	15.0	587		213	162	2066	1782	177	400				7.8
05-May-89	102	555	45.4	24.4	50	2.5	20.3	20.2	555	28	224	222	2106	1796	182	500	0.4	27	2561	
06-May-89	103	445	44.0	22.9	33	2.7	19.9	17.0	353	29	215	184	2048	1706	187	400				
07-May-89	104	530	45.6	25.4	29	3.5	19.3	20.0	314	39	213	220				500				
08-May-89	105	518	45.1	24.8	20	2.9	21.3	20.8	220	32	230	225	1948	1682	188	400		31		
09-May-89	106	555	43.7	24.5	45	1.8	21.5	20.0	494	20	237	220	2190	1870	175	500		31		7.7
AVERAGE 3		538	49.8	24.0	50	2.6	19.5	21.6	549	30	213	236	1951	1674	185	459		31	2349	7.8

APPENDIX C: DATA MEASURED IN CONTROL SYSTEM

DATE	DAY No.	MEASURED INFLUENT CONCENTRATIONS			MEASURED EFFLUENT CONCENTRATIONS				MASS IN EFFLUENT AFTER DILUTION				MLSS	MLVSS	DSVI	N ADDED	ANOX NO3	OUR	COD SLUDGE	pH
		COD mg/l	TKN mgN/l	PHOS mg/l	COD mg/l	TKN mgN/l	PHOS mg/l	NO3 mg/l	COD mg	TKN mgN	PHOS mg	NO3 mg	mg/l	mg/l	ml/g	mg	mg/l	mgO/ l/d	mg/l	
10-May-89	107	571	56.0	24.5	49	1.7	19.6	22.6	539	18	216	249	2042	1796	188	500	10.2	30		
11-May-89	108	480		24.0	40		19.9	26.0	435		215	281	1916	1694	191	400		29	2339	7.9
12-May-89	109															500				
13-May-89	110	597	61.3	25.4	65	4.8	18.8	32.8	710	52	207	361	2016	1738	190	500		35		7.7
14-May-89	111	569		23.8	44	0.8	18.8	41.0	488	9	207	451	1982	1740	193	500		33		7.7
15-May-89	112	556	56.8	24.5	52	3.1	18.3	34.0	577	34	201	374	2052	1772	187	500		38		7.7
16-May-89	113	516	57.4	24.3	48	5.3	20.4	31.2	532	59	225	343	2102	1800	182	500		29	2701	7.7
17-May-89	114	516	55.7	25.4	36	5.2	19.0	31.2	399	57	209	343	2254	1998	177	500	4.0	33	3790	7.6
18-May-89	115	527	57.7	24.5	45	3.8	19.0	30.6	491	42	209	337	2140	1840	187	500		31	2636	7.4
19-May-89	116	584	66.4	24.5	53	2.7	19.0	28.2	580	29	209	310	2244	1978	186	495		30		7.5
20-May-89	117	519	56.0	24.5		3.4		32.0		37		352	2226	1914	180	500		30		7.4
21-May-89	118	515	55.4	24.5	41	3.1	19.3	32.4	446	34	213	356				500				
22-May-89	119	487	55.2	24.5	41	4.1	19.6	30.6	446	45	216	336	2218	1926	173	495	10.0	31	2839	7.3
23-May-89	120	475	52.1	23.7	49			32.0	535			352	2074	1830	177	494		34	2718	7.4
24-May-89	121	512	55.2	24.8	45	1.0	19.9	33.6	491	11	219	369	2272	1968	161	498		36		7.3
AVERAGE 4		530	57.1	24.5	47	3.2	19.3	31.3	513	36	212	344	2118	1846	182	492	8.1	32	2837	7.5
25-May-89	122	544	74.5	25.5	57	3.4	20.0	29.2	630	37	220	321	2408	2110	166	500		35		7.4
26-May-89	123	397	51.8	24.1	57	2.9	19.3	24.8	629	32	212	273	2296	1964	167	495	5.2	34		
27-May-89	124	392	61.0	23.8	41	2.7	18.6	25.2	449	29	205	277				498		32		
28-May-89	125	347	50.1	22.8	41	3.4	18.9	28.2	450	37	208	310	2032	1746	172	500		34		7.4
29-May-89	126	380	50.1	22.4			19.3				212					498				
30-May-89	127	554	51.0	23.1	69	7.1	20.3	33.6	761	79	224	370				500		31		7.5
31-May-89	128	525	53.5	22.8	41	3.2	17.9	28.6	448	35	197	315				500				
01-Jun-89	129	521	51.2	22.4	69	1.7	18.3	27.6	761	18	201	304	2010	1724	157	500		27		7.3
02-Jun-89	130	465	52.4	24.3	62	2.1	20.5	31.2	679	23	226	343	1990	1758	160	500	8.4	26		7.3
03-Jun-89	131	526	53.5	24.0	49	2.5	19.0	31.2	540	28	208	342	2336	2050	143	478		28		
04-Jun-89	132	456	51.8	24.0	49	2.1	20.5	40.0	541	23	225	439	2198	1882	152	485		22		7.4
05-Jun-89	133	509	46.8	24.3	45	4.9	21.0	41.8	492	54	231	459	2212	1922	143	495		35		7.3
06-Jun-89	134	476	53.2	23.7		4.5	18.7	36.0		49	205	395	1852	1656	162	488		30		7.4
07-Jun-89	135	498	50.1	25.5	58	3.2	19.0	32.4	630	35	208	354	2278	2000	146	467	18.4	27		7.4
08-Jun-89	136	526	54.9	24.9	45	5.3	19.3	30.4	497	59	212	334	1868	1584	160	500		28	2590	7.5
09-Jun-89	137	368		26.1	86		21.6	29.8	941		237	327	2404	2134	139	479	12.8	23		
AVERAGE 5		468	53.7	24.0	55	3.5	19.5	31.3	603	38	214	344	2157	1878	156	493	11.2	29	2590	7.4
10-Jun-89	138	584	49.6	26.7	58	3.8	17.8	27.6	627	41	194	301				445				
11-Jun-89	139	600	46.5	25.5	95	2.4	20.6		1030	26	224		2022	1820	165	445		23		7.6
12-Jun-89	140	528	42.6	26.7	25	0.6	20.9	19.9	267	7	227	216	1818	1614	165	430	1.9	24		7.5
13-Jun-89	141	475	37.8	25.8	29	1.0	21.2	16.9	311	11	230	183	1936	1704	164	420		21		7.5
14-Jun-89	142	508	44.2	24.9	25	3.4	20.3	15.4	269	37	222	168	1824	1576	165	460		29		7.6
15-Jun-89	143	508	44.5	24.6	45	3.1	20.6	12.1	484	33	221	130	1936	1690	172	370		25		7.6
16-Jun-89	144	541	43.6	25.2	107	2.1	20.6	13.9	1152	23	223	150	2044	1760	163	410	0.3	24		
17-Jun-89	145	533	42.0	24.3	53	2.4	23.9	13.3	577	26	259	144	2054	1790	178	420		26		
18-Jun-89	146	508	44.0	24.9	49	3.1	20.0	12.5	529	33	215	135	2036	1750	164	380		28		
19-Jun-89	147	549	45.6	25.2	57	2.9	20.3	14.3	622	32	220	155	1610	1366	197	430	0.3	29		7.6
20-Jun-89	148	569	45.6	24.7	49	3.4	19.8	14.5	530	36	214	156	2068	1760	161	390				7.5
21-Jun-89	149	528	44.8	29.1	45	2.8	20.1	15.4	488	30	218	166	2096	1848	167	420		26		
22-Jun-89	150	425	43.1	26.3	49	3.8	18.6	16.6	533	41	202	181	2024	1866	165	445				7.6
23-Jun-89	151	442	43.7	23.8	45	2.5	19.2	18.2	483	27	206	196	1964	1792	170	370		28		
24-Jun-89	152	457		24.4	49	5.2	19.8	15.8	529	56	214	170	2004	1708	150	400		28		7.5
25-Jun-89	153	503	43.1	23.2	33	4.3	19.5	16.6	355	47	212	181				430				
26-Jun-89	154	482	60.5	23.2	45	2.7	19.5	20.9	483	29	210	225	2850	1716	154	375	12.1	25		
27-Jun-89	155	454	44.5		41	3.8	18.6	40.0	443	41	202	434	2138	1840	156	425		22		
28-Jun-89	156	503	49.3	24.6	49	5.7	20.2	22.3	535	63	221	243	1958	1738	153	455		22		
29-Jun-89	157	446	40.9	24.9	41		20.9	22.0	439		225	237	2596	2280	116	385		20		
AVERAGE 6		507	45.0	25.2	49	3.1	20.1	18.3	534	34	218	198	2054	1757	162	415	3.6	25		7.5
30-Jun-89	158	499	59.9	24.9	37	6.9	20.2	20.3	390	73	214	215	2128	1820	149	300	15.0	23		7.4
01-Jul-89	159	478	66.1	24.3	36	6.0	19.9	20.6	400	66	219	226	2038	1850	147	495		26		7.4

APPENDIX C: DATA MEASURED IN CONTROL SYSTEM

DATE	DAY No.	MEASURED INFLUENT CONCENTRATIONS			MEASURED EFFLUENT CONCENTRATIONS				MASS IN EFFLUENT AFTER DILUTION				MLSS	MLVSS	DSVI	N ADDED	ANOX NO3	OUR	COD SLUDGE	pH
		COD mg/l	TKN mgN/l	PHOS mg/l	COD mg/l	TKN mgN/l	PHOS mg/l	NO3 mg/l	COD mg	TKN mgN	PHOS mg	NO3 mg	mg/l	mg/l	ml/g	mg	mg/l	mgO/ l/d	mg/l	
02-Jul-89	160	538	60.5	24.9	53	3.6	19.9	24.4	570	39	216	265				415				
03-Jul-89	161	502	66.4	24.0	32	4.1	20.2	25.0	351	45	219	271	2062	1820	137	415	8.2	28		
04-Jul-89	162	478	58.2	24.0	49	2.8	18.4	26.2	526	30	199	284	2016	1824	140	415		24		7.5
05-Jul-89	163	522	61.2	25.2	49	4.8	18.6	25.6	525	51	201	277	1824	1656	146	405		32	2307	7.4
06-Jul-89	164	514	60.8	24.2	77	2.5		26.2	833	27		284	1848	1634	144	415		26	2469	
07-Jul-89	165	531	58.2	24.5	41	4.8	20.0	27.2	450	52	220	299	2202	1914	121	500	11.5	29	2862	7.5
08-Jul-89	166	548	62.2	24.8	33	4.8	19.4	26.8	360	52	214	295	2768	2148	108	500		26		
09-Jul-89	167	556		25.7	45		20.0	26.8	495		220	295				500				
10-Jul-89	168	556	56.3	26.0	53		21.2		562		224		2352	2036	120	285		35		
11-Jul-89	169	499	54.6	26.3	49	7.7	21.2	15.8	516	81	223	166	2100	1806	131	260		29		7.3
12-Jul-89	170	524	54.0	26.9	49	5.7	21.8	20.1	523	61	233	214	2292	1972	125	330		32	2943	
13-Jul-89	171	522	55.4	27.3	45	2.8	22.7	19.0	477	30	241	202	2310	2038	130	310		34	2938	
14-Jul-89	172	543	54.0	29.1	57	3.4	23.0	19.4	609	36	246	207	2074	1802	127	335	1.6	30		7.4
15-Jul-89	173				53	3.6	23.9	19.4	558	38	252	204	2380	2050	121	260		31		
16-Jul-89	174	518	52.1	26.7	37	2.8	22.7	18.6	392	30	242	198				335		29		7.6
17-Jul-89	175	506	46.5	30.7	37	2.7	22.4	19.6	397	29	242	212	2104	1816	131	400		28		
18-Jul-89	176	514	48.2	25.8	12	3.1	22.4	19.4	131	33	239	207	1992	1640	132	340		29	3060	7.4
19-Jul-89	177	519	54.0	25.2	45	5.0	21.8	17.0	474	53	230	180	2910	2438	103	285	0.1	35		
AVERAGE 7		519	57.0	25.8	44	4.3	21	22	477	46	226	237	2200	1898		381		29		
20-Jul-89	178	511	48.7	26.1	57	1.5	21.2	23.0	629	17	233	253	2402	2086	115	495		33		
21-Jul-89	179	511	48.4	25.8	45	3.5	21.5	22.2	472	37	225	233	2240	1940	117	245		31		
22-Jul-89	180	507	45.6	25.2												500				
23-Jul-89	181	507	46.5	23.8	41	13.3	18.0	18.6	450	146	198	205	2610	2252	110	500				
24-Jul-89	182	495	44.5	24.1	37	7.3	19.2	9.4	402	80	210	103	1844	1640	122	470		30		7.4
25-Jul-89	183	510	42.3	24.1	37	3.5	19.2	22.0	393	37	206	236	1902	1674	125	355		30	2723	
26-Jul-89	184	524	40.9	25.7	85	3.4	19.5	20.2	915	36	209	217		1728		360	2.8	27		
27-Jul-89	185	524	45.4	24.7	45	4.8	19.2	19.4	479	51	206	208	2058	1772	109	360		31		7.4
28-Jul-89	186	536	46.2	29.3	41	3.2	19.5		435	34	209		2296	1968	103	355	7.2	32		
29-Jul-89	187	516	53.5	29.0	28	3.8	20.1	24.4	302	40	214	259	2288	1788	104	315		35		
30-Jul-89	188	475	42.8	29.3	53	3.5	20.5	24.2	564	37	219	258	2242	1822	100	335		31		
31-Jul-89	189	423	44.0	29.3	28	3.6	19.5	26.2	308	39	211	283	1912	1828	118	405	6.6	31		
01-Aug-89	190	451	42.6		45	3.1	18.8	26.4	479	33	201	283	2062	1730	109	355		28	2560	7.5
02-Aug-89	191	511	47.0	25.4									2040	1644	104	475				
03-Aug-89	192	515	46.2	25.4	41	4.6	19.7	24.2	436	50	212	260	2192	1804	91	370		30		
04-Aug-89	193	430	50.1	24.7	45	4.1	20.0	17.8	480	44	215	191	2216	1826	102	365		34		
AVERAGE 8		497	45.9	26.1	44.8	4.5	19.7	21.4	482	49	212	230	2165	1833	109	391	6	31	2642	7.5
05-Aug-89	194	539	51.0	25.1	41	2.0	21.0	17.4	435	21	225	186	2484	2220	96	355		32		7.4
06-Aug-89	195	527	46.2	25.4	53	2.8	20.3	16.8	569	30	219	181				395				
07-Aug-89	196	491	46.2	24.1	41	3.5	20.0	18.0	436	38	215	194	1930	1630	104	380	1.8	34		
08-Aug-89	197	519	45.6	24.7	158	1.7	20.0	15.8	1702	18	215	170	2420	1960	88	380		32		
09-Aug-89	198	492		24.7	41	2.2	20.3	15.8	444	24	220	171	2266	2048	99	410		32		
10-Aug-89	199	496	42.0	25.4	123	2.9	20.0	15.6	1317	32	215	167	2348	2072	96	360		32	2990	
11-Aug-89	200	519		24.7	46	2.9	20.5	18.2	494	32	222	197	1970	1882	107	405		29		7.4
12-Aug-89	201	515	46.2	24.5	42	4.2	19.9	16.8	448	45	215	181				390		33		
13-Aug-89	202	498	47.9	23.3	120		19.9	18.0	1302		215	195				405				
14-Aug-89	203	536	54.0	24.3	50		19.6	18.2	540		212	197	2966	2524	86	415		37		
15-Aug-89	204		43.1	25.2		3.2	20.2	19.8		35	221	216	2200	1934	91	455	6.0	34	2906	
16-Aug-89	205	536	49.3	24.5	50	2.9	20.5	19.6	541	32	223	213				430				
17-Aug-89	206	507	42.0	24.5	58	10.4	21.5	15.6	632	113	233	170	1876		89	435				
18-Aug-89	207	511	42.8	24.2	50	3.2	20.5	20.4	534	34	220	218	1962	1646	107	355		40		
19-Aug-89	208	455	45.9	25.2	61		20.5	22.6	662		221	243	1912	1590		385		32		
20-Aug-89	209	504	46.5	27.6	53		20.5	22.6	579		223	246				435				
21-Aug-89	210	493	46.2	25.7	41	3.9	21.3	22.6	448	43	232	246	1872	1678	96	445	11.6	33		7.4
22-Aug-89	211		48.2	26.7	53		21.6	24.4	577		233	263	1774	1510	96	395				
23-Aug-89	212	473	49.0	24.8	53	1.7	20.7	28.8	583	19	225	314	1742	1562	103	450		31		
24-Aug-89	213	510	51.8	26.7	45	2.7	20.7	26.2	487	29	222	282	1890	1648	85	380				7.3
25-Aug-89	214	498		24.5	62	3.2	20.7	25.2	670	35	224	274			96	430	10.4	32		
26-Aug-89	215	518	53.2	24.5	33	3.5	21.0	27.0	354	38	226	291	2184	1764	85	385				

APPENDIX C: DATA MEASURED IN CONTROL SYSTEM

DATE	DAY No.	MEASURED INFLUENT CONCENTRATIONS			MEASURED EFFLUENT CONCENTRATIONS				MASS IN EFFLUENT AFTER DILUTION				MLSS	MLVSS	DSVI	N ADDED	ANOX NO3	OUR	COD SLUDGE	pH
		COD mg/l	TKN mgN/l	PHOS mg/l	COD mg/l	TKN mgN/l	PHOS mg/l	NO3 mg/l	COD mg	TKN mgN	PHOS mg	NO3 mg	mg/l	mg/l	ml/g	mg	mg/l	mgO/ l/d	mg/l	
27-Aug-89	216	493	51.0	24.5	90		20.3	27.0	979		220	292	2068	1714	86	410		34		
28-Aug-89	217	493	50.1	25.1	45	2.4	20.3	29.6	496	26	224	326	1774	1630	97	500				
29-Aug-89	218	500	52.4	23.2	49	2.4	19.7	29.6	528	26	212	318	1914	1690	97	370		35		
30-Aug-89	219	504	49.6	25.4	53	3.4	19.1	21.8	582	37	208	238	2710	2244	74	465		34		
31-Aug-89	220	512	52.1	23.2	53	4.8	18.7	18.8	578	52	203	204	2158	1868	89	430		33		
AVERAGE 9		505	48.0	24.9	60	3.3	20.4	21.2	651	36	220	229	2115	1841	94	409		33	2948	7.4
01-Sep-89	221	492	54.0	24.1	49		19.0	19.2	529		204	207	1982	1664	90	380		42		
02-Sep-89	222	384	44.5	24.1		13.3	19.9	13.4		142	212	143				335				
03-Sep-89	223	504	41.7	26.8		2.1	20.2	19.6		23	220	214				450				
04-Sep-89	224	430	41.7		45		22.0	19.2	486		237	207	2738	2276	78	395		35		
05-Sep-89	225	483	36.1	23.5	45	3.5	20.5	22.2	488	38	222	240	2214	1844	81	415		33		
06-Sep-89	226	504	41.7	24.7	37	5.3	19.9	22.2	404	58	218	243	1628	1442	88	480		20		
07-Sep-89	227	500	38.6	24.7	33	3.1	18.7	40.0	360	34	205	440	1468	1280	94	500				
08-Sep-89	228	545	66.6	24.1	74	3.5	19.0	34.8	811	39	208	383	2080	1544	72	500		27		7.2
09-Sep-89	229	459	41.4	24.1	29	2.9	19.3	35.0	315	32	212	385	1436	1200	99	500		34		
10-Sep-89	230	461	39.2	23.5	53	5.3	18.9	25.0	565	57	203	268	1432	1298	100	365		31		
11-Sep-89	231	461	39.2				19.3	30.6			211	335	1690	1496	93	480	32.6	29		
12-Sep-89	232	441	44.8	23.9	49	1.3	20.9	44.6	538	14	230	490	1894	1672	87	490				
AVERAGE 10		472	44.1	24.3	46	4.5	19.8	27.2	500	49	215	296	1856	1572	88	441		31		7.2
13-Sep-89	233	457	44.0	24.5	49	3.1	18.6	32.0	536	34	204	350	1710	1406	96	475		34		
14-Sep-89	234	481	43.7	26.8	53	5.9	22.2		578	64	242		1986	1708	86	450		32		7.5
15-Sep-89	235	481	45.9	32.7	37	4.5	25.8	20.0	388	47	273	211	1542	1352	93	280				7.4
16-Sep-89	236	461	40.3	39.6	41	7.8	18.0	22.2	443	85	195	241	1550	1236	101	430		29		
17-Sep-89	237	461	42.6	14.4	37	3.4	23.5	27.4	402	37	257	300	1764	1370	97	470		33		
18-Sep-89	238	405	38.1	36.3	69	8.5	24.5	23.4	757	94	270	257	1530	1376	121	500		33		
19-Sep-89	239	457	36.7	14.4	32	4.2	20.9	26.4	355	46	230	290				500				
20-Sep-89	240	453	40.6	35.9	61	4.2	21.3	34.6	668	46	234	381	1968	1752	102	500		29		
AVERAGE 11		457	41.5	28.1	47	5.2	21.9	26.6	516	57	238	290	1721	1457	99	451		32		7.5
21-Sep-89	241	457	52.1	10.6	69	8.1	22.2	26.4	745	88	240	286				410	22.8	27		
22-Sep-89	242	441	51.2	35.3	41	11.1	19.4	17.4	405	111	194	174	1812	1620	126	0	2.4	29		
23-Sep-89	243	467	52.4	13.4	45	17.5	19.7	22.6	492	193	217	249	1764	1572	126	500				7.5
24-Sep-89	244	474		13.4	24	25.5	20.9	21.2	266	279	229	232	1936	1558	133	475				
25-Sep-89	245	433	54.3	13.4	52	11.2	19.1	33.6	574	123	209	369				495	17.2	28		
26-Sep-89	246	488	50.7	34.4	61	12.0	18.4	32.0	671	132	203	352	1804	1508	139	500	27.6	28		7.5
27-Sep-89	247	483	36.1	12.9			20.9	40.4			230	444	1614	1380	155	500		24		
28-Sep-89	248	496	41.7	36.3	41	4.9	19.7		447	54	217		2056	1764	132	500		24		
29-Sep-89	249	548	42.3	10.3	53	1.1	22.5		580	12	248		1904	1540	128	500				7.5
30-Sep-89	250	471	37.5	34.7	57	5.2	18.4	19.8	626	57	202	218	2152	1704	123	500				
01-Oct-89	251	496	40.3	11.2	57	2.1	19.1		626	23	210		1838	1514	167	500				
02-Oct-89	252	496	40.9	34.1	37	4.2	17.2		402	46	189		1804	1476	162	500		24		
03-Oct-89	253	504	44.5	11.6	41	2.9	20.3	16.2	447	32	223	178	2122			500		25		7.6
04-Oct-89	254	491	37.5	36.6	53	2.7	18.7	21.8	578	29	205	239	1971	1612	173	480		23	2393	
05-Oct-89	255	462	37.8	10.0	41	4.6	19.7	20.4	439	50	213	221	1752	1460	188	410		25		7.5
06-Oct-89	256	491	40.0	34.1	45	4.2	19.4	20.8	491	46	213	229	1994	1624	181	500		23	2474	
07-Oct-89	257	438	38.1	10.0	41		19.7	20.6	438		213	222	2060	1778	167	400		24		
08-Oct-89	258	479	38.9	35.2	41		19.1	25.8	446		210	284	1960	1608	193	500				
09-Oct-89	259	475	37.2	11.0	41	2.1	20.5	37.2	446	23	225	409	1768	1590	201	500		25		7.5
10-Oct-89	260	531	40.9	39.0	41	2.2	21.8	22.6	446	25	239	249	2718	1958	143	500				
11-Oct-89	261				45	3.6	22.1	21.4	484	39	239	232	2046	1804	185	425		27		
12-Oct-89	262	487	42.8	41.9	61	3.5	21.4	19.2	664	38	234	210	1910	1642	198	460		25		
AVERAGE 12		490	39.8	24.6	46	3.3	20.0	23.9	504	37	219	261	1979	1630	166	480		25	2434	7.5
13-Oct-89	263	557		13.0	41	3.5	22.1	23.0	446	39	243	253	1800	1554	198	500	8.3	25		7.6
14-Oct-89	264	519		11.7	61		12.6	20.4	656		137	220	1944	1622	211	400		23		

APPENDIX C: DATA MEASURED IN CONTROL SYSTEM

DATE	DAY No.	MEASURED INFLUENT CONCENTRATIONS			MEASURED EFFLUENT CONCENTRATIONS				MASS IN EFFLUENT AFTER DILUTION				MLSS	MLVSS	DSVI	N ADDED	ANOX NO3	OUR	COD SLUDGE	pH
		COD mg/l	TKN mgN/l	PHOS mg/l	COD mg/l	TKN mgN/l	PHOS mg/l	NO3 mg/l	COD mg	TKN mgN	PHOS mg	NO3 mg	mg/l	mg/l	ml/g	mg	mg/l	mgO/ l/d	mg/l	
15-Oct-89	265	555	63.6	11.7	36	3.8	9.7	23.0	401	42	107	253	2128	1806	178	500		28		
16-Oct-89	266	538	44.2	11.3	57	2.1	8.7	25.0	624	23	96	275	2094	1800	202	500		28		7.5
17-Oct-89	267	542	44.2	11.7	53	2.7	7.8	26.6	579	29	85	293	2144	1874	213	500		26		
18-Oct-89	268	514	39.2	10.7	41	2.7	5.5	22.0	424	28	57	230	2144	1814	228	235		24		
19-Oct-89	269	530	43.7	11.0	37	3.2	7.7	24.6	397	35	83	266	2230	1928	219	400				7.4
20-Oct-89	270	543	42.6	11.9	20	2.2	7.1	33.8	224	25	78	372	2030	1688	241	500		31		
21-Oct-89	271	481	44.2	11.0	45	2.8	7.1	31.0	494	31	78	341	2434	2084	228	500		27		
22-Oct-89	272	551	40.3	10.7	33	3.4	7.1	28.2	359	37	78	310	2220	1872	240	500		26		7.5
23-Oct-89	273	575	44.2	11.0	33	2.4	7.1	32.4	359	26	78	356	2346	1990	242	500		24		
24-Oct-89	274	530	45.4	11.0	41	3.2	7.7	18.2	447	35	84	199	2296	1916	232	475		27		
25-Oct-89	275	522		11.0	45	3.8	6.8	21.8	493	42	74	239	2322	2060	235	490	5.1			
26-Oct-89	276	469	36.7	10.1	45	8.7	6.8	16.6	494	95	74	183	2298	2066	256	500		26		
27-Oct-89	277	522	37.8	10.4	45	3.1	6.8	18.6	486	33	73	201	2446	2140	232	410	7.0			7.7
28-Oct-89	278	530		10.1	57	4.8	6.8	19.4	628	52	74	213	2430	2050	229	500		30		
29-Oct-89	279	571	38.6	11.3	45	3.2	7.8	29.4	494	35	86	323				500				7.6
30-Oct-89	280	551	35.6	10.8	45	2.7	7.8	26.0	494	29	86	286	2272	1976	215	500	3.8	29		
31-Oct-89	281	555	37.0	11.7	37	2.4	8.0	27.6	404	26	87	304	1870		273	500	0.8	32		7.5
01-Nov-89	282	514	36.1	11.0	45	0.4	8.0	21.2	493	5	87	233	2158	1956	260	495	6.8	17		7.6
02-Nov-89	283	470	45.1	11.3	25	3.9	7.8	20.2	270	43	86	222	2080	1818	235	500		17		
03-Nov-89	284	503	35.8	11.3	29	5.3	8.1	22.4	315	59	89	246	2246	1982	228	500		25		
AVERAGE 13		521	37.8	10.9	42	3.8	7.4	22.3	457	42	82	245	2236	2006	240	490		25		7.6
04-Nov-89	285	442	36.1	8.7		3.1	7.5	22.2		34	82	244				500				
05-Nov-89	286	600	34.7	24.8	33	1.4	11.4	21.6	359	15	126	238				500				
06-Nov-89	287	506	38.4	10.7	29	2.4	14.2	32.2	314	26	156	354	2578	2162	241	500		23		7.7
07-Nov-89	288	437	38.1	8.5		4.1	10.0	24.6		45	110	271	2282	1920	252	500	15.2	23		7.7
08-Nov-89	289	438	35.8	8.5	41		7.4	31.4	455		81	345	2410	1994	249	495		22		
09-Nov-89	290	466	41.4	8.8	25	4.6	6.6		272	51	73		2244	1960	267	500		26	2890	7.5
10-Nov-89	291	433	42.0	8.6	37	5.2	6.6		368	52	66		2410	2066	263			22		
11-Nov-89	292	421	40.0	8.8	25	5.5	6.8	22.2	265	58	73	238	2460	2308	244	350	8.4	22		
12-Nov-89	293			8.8			6.5	30.2			71	332				500				
13-Nov-89	294	458	40.3	9.4	58	9.4	7.0	32.0	636	103	76	352	1886	1696	225	500		25		7.5
14-Nov-89	295	439	38.9	9.3	58	6.2	7.1	29.8	635	68	78	328	2430	2096	219	495				
15-Nov-89	296	466	56.6	9.3	45	6.9	7.0	16.0	488	74	75	172	2504	2124	225	375		23		
AVERAGE 14		464	40.2	10.3	39	4.9	8.2	26.2	421	53	89	287	2356	2036	243	474		23	2890	7.6
16-Nov-89	297	499	56.0	9.6	86	2.8	7.0	15.0	907	30	73	159	2252	1948	228	285		26		
17-Nov-89	298	480	55.2	9.7			5.3	20.8			58	227	2344	1980	219	450		29		7.4
18-Nov-89	299	443		7.6			5.3	23.8			57	256	2320	1958	209	370		30		
19-Nov-89	300		50.7	7.2		3.9	5.3	21.2		42	57	227	2585	2136	199	360				
20-Nov-89	301	566		7.2		4.3	5.3	21.0		47	57	226	2112	1810	203	380	7.5	29		7.4
21-Nov-89	302	474	44.8	7.2	37	3.2	5.4	22.6	394	35	58	242	1906	1620	181	360		30		
22-Nov-89	303	474	45.6	7.2	49	5.2	5.3	36.2	540	57	58	398	2104	1776	202	500	15.1	23		
23-Nov-89	304	417	48.4	7.4	37	3.5	5.2	29.0	395	38	56	312	2020	1776	198	375	25.0	29		7.4
24-Nov-89	305	478		7.1	29		5.1	29.0	298		53	302	2156	1912	175	215				
AVERAGE 15		479	50.1	7.8	47	3.8	5.5	24.3	507	41	59	261	2200	1880	202	366		28		7.4
25-Nov-89	306	474	50.7													500				7.4
26-Nov-89	307				37		5.0	18.4	406		55	202	2070	1757	188	500				
27-Nov-89	308	497	56.6		49	5.0	5.1	17.4	540	55	56	191	2016	1724	187	485				
28-Nov-89	309	484	50.7		45	3.1	5.2	15.0	492	34	57	164	2734	2330	203	455				
29-Nov-89	310																			
30-Nov-89	311																			

APPENDIX C: DATA MEASURED IN EXPERIMENTAL SYSTEM

DATE / STEADY STATE PERIOD No	DAY No.	MEASURED INFLUENT CONCENTRATIONS			MEASURED EFFLUENT CONCENTRATIONS				MASS IN EFFLUENT AFTER DILUTION				MLSS	MLVSS	DSVI	N ADDED	ANOX NO3	OUR	COD SLUDGE	pH
		COD mg/l	TKN mgN/l	PHOS mg/l	COD mg/l	TKN mgN/l	PHOS mg/l	NO3 mg/l	COD mg	TKN mgN	PHOS mg	NO3 mg	mg/l	mg/l	ml/g	mg	mg/l	mgO/ l/d	mg/l	
15 l INF.																				
24-Jan-89	1	589	61.6		108	46.1		7.4	1077	461		74								
25-Jan-89	2	591			59			6.8	589			68	3314	2766	211					
26-Jan-89	3	585			69			5.0	690			50	2522	2148	211					7.7
27-Jan-89	4	585	52.9		99	19.5		4.2	990	195		42	4122	3448	212					7.6
28-Jan-89	5	412	49.6		61	20.7		4.0	610	207		40	3094	2652	205					
29-Jan-89	6																			
30-Jan-89	7	559	67.5		73	22.5		2.8	730	225		28	4068	3312	155					7.6
31-Jan-89	8	563	55.0		69	20.7		3.8	694	207		38	3614	2992	184					7.7
01-Feb-89	9	518	46.2		61	13.2		5.0	612	132		50	2708	2708	177					7.6
02-Feb-89	10	486	40.6		51	9.0		3.6	510	90		36	3200	2588	208					7.6
03-Feb-89	11	333	40.6		36	3.9	13.7	2.8	363	39	137	28	3454	2832						7.5
04-Feb-89	12	483	40.0		48	3.4		3.4	484	34		34	3094	2394	205					
05-Feb-89	13																			
06-Feb-89	14	510	50.0		63	6.0		3.0	625	60		30	3576	2948	196					7.5
07-Feb-89	15	488	42.6	24.8	56	4.6	12.8	2.2	564	46	128	22	3300	2644	176					7.6
08-Feb-89	16												2494	2018	200					7.7
09-Feb-89	17	399	41.3	26.3	54	4.6	17.6	8.8	544	46	176	88	3024	2430	187					7.8
ADD NO3																				
10-Feb-89	18	425	45.6	26.9	34	4.2	3.6	9.2	343	42	36	92	3062	2488	185					7.6
11-Feb-89	19	479	42.0	25.2	28	4.9	6.0	10.0	284	49	60	100	2656	2116	216					7.7
12-Feb-89	20																			
13-Feb-89	21	349	46.6	24.4	37	4.4	19.2	16.0	366	44	192	160	3192	2570	214					7.7
14-Feb-89	22	463	48.3	22.8	47	4.8	22.8	15.4	467	48	228	154	3532	2812	198		1.0			
15-Feb-89	23	480	52.1	26.4	35	5.2	19.8	21.2	345	52	198	212	3282	2616	203					7.6
16-Feb-89	24	478	49.1	26.0	39	4.1	20.8	16.6	386	41	208	166	3180	2546	225					7.5
17-Feb-89	25				31		21.6	13.4	320		227	141	3264	2664	204	250	0.4			
18-Feb-89	26			23.2			20.4	8.4			214	88	2766	2266	223	250				
19-Feb-89	27															250				
20-Feb-89	28	463	38.9	23.3	57	3.1	19.0	6.6	569	31	190	66	3408	2766	210		0.0			
21-Feb-89	29	488	40.3	24.4	45	2.5	18.2		473	26	191		3396	2768	206	250				
22-Feb-89	30			23.8			19.6	7.0			196	70								
10 l INF.																				
23-Feb-89	31	522	44.0	32.1	30	5.0	23.0	12.8	330	55	253	141	2722	2296	208	500	0.8			
24-Feb-89	32	611	45.8	33.2	79	1.5	24.7	14.0	869	17	272	154	2856	2402	227	500				8.0
25-Feb-89	33	514	44.4	33.2	41	4.2	29.3	14.0	417	43	302	144	2450	2032	244	150				7.9
26-Feb-89	34																			
27-Feb-89	35	516	45.2	32.8	40	4.8	28.4	15.0	436	52	310	164	2914	2374	223	450	5.6			7.9
28-Feb-89	36	503	41.6	31.6	40	4.6	29.6	20.0	440	51	326	220	2696	2296	247	500				7.8
01-Mar-89	37	454	43.0	31.6	52	3.0	26.8	23.6	572	33	295	260	2806	2360	237	500	10.6			
02-Mar-89	38	507	42.0	34.6	25	4.0	27.6	19.6	271	43	299	213	2738	2250	238	425				7.8
03-Mar-89	39	514	45.0	31.2	46	4.0	27.4	19.2	502	44	299	209	2556	2202	248	450	8.2			7.8
04-Mar-89	40	505		33.0	25	0.0	28.0	18.0	276		307	197	2756	2306	224	475				7.8
05-Mar-89	41	520	44.0	32.8	34	3.6	26.3	18.2	369	40	289	200	2864	2408	209	500				7.8
06-Mar-89	42	528	46.5	33.7	55	4.9	27.7	15.6	589	53	299	168	2632	2256	215	400	3.0			7.7
07-Mar-89	43	533	38.9	32.8	30	0.0	26.3	16.2	326		284	175	2782	2340	204	400				7.7
AVERAGE		519	43.7	32.7	41	3.3	27.1	17.2	450	43	294	187	2731	2294	227	438	6			
08-Mar-89	44	505	55.4	33.7	30	3.2	25.2	18.0	323	35	273	195	2848	2406	199	425	6.6			7.6
09-Mar-89	45	535	57.7	32.8	81	4.1	26.3	21.1	886	45	289	232	2516	2106		500				7.7
10-Mar-89	46	533	58.0	24.3	42	0.6	22.6	22.9	465	6	249	250	2806	2320	196	450	7.7			7.7
11-Mar-89	47	541	57.7	25.9	58	9.0	21.2	25.2	647	100	236	277	2726	2232	196	500			3012	7.7
12-Mar-89	48	503	57.7	26.5	32	3.2	18.9	21.9	347	35	204	234	2848	2408	187	350				7.6
13-Mar-89	49	538	59.8	26.8	16	3.5	18.6	21.1	175	38	203	228	2688	2250		400				
14-Mar-89	50	506	59.2	25.9	8	3.5	18.3	23.8	88	39	201	259	3144	2592	190	450				7.5
15-Mar-89	51	502	58.1	25.3	16	2.9	17.4	28.1	179	32	193	309	2966	2438	185	500	7.1			
16-Mar-89	52	480	57.0	24.4	22	4.6	17.1	25.0	244	51	189	274	3130	2520	181	475				7.6
17-Mar-89	53	518	58.1	24.7	46	3.5	16.6	26.2	513	39	184	288	3158	2574	184	500	8.8			7.7
18-Mar-89	54		62.7	24.9		5.0	16.8	26.8		55	185	292	3006	2422	194	450				7.5
19-Mar-89	55	578	61.9	25.1	57	3.6	16.1	26.8	638	40	178	295	3030	2366	198	500				

APPENDIX C: DATA MEASURED IN EXPERIMENTAL SYSTEM

DATE / STEADY STATE PERIOD No	DAY No.	MEASURED INFLUENT CONCENTRATIONS			MEASURED EFFLUENT CONCENTRATIONS				MASS IN EFFLUENT AFTER DILUTION				MLSS	MLVSS	DSVI	N ADDED	ANOX NO3	OUR mgO/l/d	COD SLUDGE	pH
		COD mg/l	TKN mgN/l	PHOS mg/l	COD mg/l	TKN mgN/l	PHOS mg/l	NO3 mg/l	COD mg	TKN mgN	PHOS mg	NO3 mg	mg/l	mg/l	ml/g	mg	mg/l		mg/l	
20-Mar-89	56	566	61.9	24.8	56	3.6	14.9	28.6	613	39	163	309	3344	2690	185	400	10.2			7.3
21-Mar-89	57	529	59.1	24.5	49	4.3	17.8	27.0	538	47	195	294	3208	2540	192	450			3258	
22-Mar-89	58	550	59.9	24.0	73	3.5	16.4	27.4	814	39	181	301	3334	2648	180	500	10.6			
AVERAGE		527	58.9	26.2	42	3.9	18.9	24.7	462	43	209	269	2983	2434	190	457	9		3135	7.6
23-Mar-89	59	579	59.1	23.4	172	2.9	17.2	28.4	1913	32	191	312	2552	2054	183	500				
24-Mar-89	60	616	56.6	24.0	74	3.4	16.9	32.2	820	37	188	354	2768	2224	192	500				
25-Mar-89	61	566	54.0	23.7	33	3.9	15.5	28.4	362	44	172	312	1872	1426	178	500				
26-Mar-89	62	533	54.6	23.1	82	3.8	15.2	35.2	909	42	169	387	3186	2444	167	500				
27-Mar-89	63	582	59.1	24.5	24	2.9			271	33						500				
28-Mar-89	64	562	54.3	23.7	61	3.9	15.8	30.4	678	44	175	334	2992	2354	173	500				
29-Mar-89	65	619	54.6	23.5	102	3.1	15.2	25.0	1137	34	169	275	3256	2564	163	500				7.5
30-Mar-89	66	529	51.0	23.8	90	9.9	16.7	27.0	994	110	185	297	3004	2342	178	500				
31-Mar-89	67	542	51.0	22.9	66		15.5	25.0	729		172	275	2996	2300	161	500		29		
01-Apr-89	68	575	52.4	23.2	49	2.7	15.8	25.6	547	30	175	282	2940	2244	170	500				
02-Apr-89	69	591	50.7	21.8	57	2.5	15.5	25.0	638	28	172	275	2800	2166	167	500		41		
03-Apr-89	70	532	50.1	23.5	66	3.1	18.7	21.8	727	34	207	240	2866	2228	157	500		33	2984	
04-Apr-89	71	564	57.4	24.3	81	3.8	15.8	23.8	895	42	175	262	2918	2278	160	500		43		
05-Apr-89	72	524		23.5	60		15.8	24.6	671		175	271	2998	2342	161	500	9.8	31		
06-Apr-89	73	552	52.9	25.5	61	2.2	16.4	24.2	682	25	182	266	3040	2304	159	500		26		
AVERAGE 1		564	54	24	72	4	16	27	798	41	179	296	2871	2234	169	500		34	2984	7.5
07-Apr-89	74	504	38.1	23.3	65	5.5	15.3	21.0	716	61	169	231	2582	2026	168	500		23		
08-Apr-89	75	508	31.9	23.9	52	5.9	18.6	10.8	582	65	206	119	2822	2138	171	500				
09-Apr-89	76	544	38.9	25.5	60	3.8	17.5	10.4	641	40	185	109	3042	2460	164	250				
10-Apr-89	77	544	28.2		73	3.4	17.2	8.8	769	36	182	92	2886	2162	158	250		31		
11-Apr-89	78	523	38.4	24.1	94	3.9	16.9	9.2	1020	42	183	98	3056	2364	153	350		27	3306	
12-Apr-89	79	535	38.9	24.7	98	2.9	16.4	11.4	1082	32	180	124	3110	2386	150	450	2.8	30		
13-Apr-89	80	508	33.6	20.2	83	2.7	16.1	13.8	918	30	179	152	3028	2346	149	500		27		
14-Apr-89	81	504	37.2	25.3	71	2.4	16.5	12.4	772	26	180	134	2722	2056	171	400		23		
15-Apr-89	82	531	43.7	24.8	39	3.2	16.8	10.8	433	35	184	118	2748	2136	158	450				
16-Apr-89	83	578	38.4	25.3	94	2.7	16.5	11.2	1046	30	183	123	3070	2292	147	500				
17-Apr-89	84	434	35.6	24.5	86	3.8	16.2	9.8	929	41	175	105	2926	2252	148	350		33		
18-Apr-89	85	483	39.2	25.6	160	2.5	18.0	12.4	1773	28	199	136	2932	2198	155	500		28	3113	
19-Apr-89	86	557	38.1	25.1	70	4.5	16.8	13.2	773	50	186	145	3036	2316	154	500	4.4	24	3195	
AVERAGE 2		520	37	24	80	4	17	12	881	40	184	130	2920	2241	157	423		27	3205	
20-Apr-89	87	500	52.9	24.8	164	3.4	16.8	19.8	1819	37	186	220	2376	1856	154	500		24		7.5
21-Apr-89	88	573	53.8	24.0	66	2.7	15.3	17.6	714	29	167	192	2674	1996	162	400	8	26		
22-Apr-89	89	612	53.2	22.9	126		15.1	31.6	1396		167	351				500			2799	
23-Apr-89	90			24.0			15.3	30.0			169	330	2748	2046	164	450		31		
24-Apr-89	91	544	56.3	24.0	45	3.4	15.1	34.0	495	37	167	377	2734	2102	159	500	15	30		8.1
25-Apr-89	92	553	52.6	23.2	141	3.9	16.5	29.4	1570	44	183	326	2734	2078	165	500		29	2746	7.9
26-Apr-89	93	542	55.4			3.2		28.0		36		311	2900	2160	172	500		39		7.2
27-Apr-89	94	595	51.2	23.5	75	2.2	15.9	13.6	830	25	176	150	2740	2098	158	500		29	2799	7.7
28-Apr-89	95	553	56.0	24.6	74	4.5	15.9	23.2	815	50	176	256	2834	2130	165	500	8	26	2785	8.0
29-Apr-89	96	498		23.0				21.6				237				450				
30-Apr-89	97	549	41.0	24.4	139		15.6		1525		171					450				
01-May-89	98	528	55.7	24.1	41	2.7	17.4	23.2	453	29	192	256	2824	2116	153	500	6	34		7.6
02-May-89	99	557	54.3	23.3	324	1.1	16.2	23.0	3576	12	179	254	3134	2450	144	500		31		
03-May-89	100	512	46.8	25.0	70	3.4	16.8	20.8	769	37	186	230	2768	1982	163	500		28	3031	
04-May-89	101	508	44.0	23.3	58	6.2	16.2	17.0	631	67	176	184	3034	2296	154	400				7.7
05-May-89	102	555	45.4	24.4	50	3.1	16.5	18.6	557	34	183	206	3146	2312	148	500	3	28	2600	
06-May-89	103	445	44.0	22.9	37	2.4	16.1	19.0	400	26	175	207	2978	2140	157	425				
07-May-89	104	530	45.6	25.4	49	3.8	16.1	21.8	541	42	177	241				500				
08-May-89	105	518	45.1	24.8	24	1.1	17.4	20.8	267	12	190	227	2984	2192	140	425		30	2734	
09-May-89	106	555	43.7	24.5	57	2.0	17.4	18.2	625	21	191	199	3020	2238	132	450		26		7.8
AVERAGE 3		538	49.8	24.0	91	3.1	16.2	22.7	999	34	178	250	2852	2137	156	473		29	2785	7.7

APPENDIX C: DATA MEASURED IN EXPERIMENTAL SYSTEM

DATE / STEADY STATE PERIOD No	DAY No.	MEASURED INFLUENT CONCENTRATIONS			MEASURED EFFLUENT CONCENTRATIONS				MASS IN EFFLUENT AFTER DILUTION				MLSS	MLVSS	DSVI	N ADDED	ANOX NO3	OUR	COD SLUDGE	pH
		COD mg/l	TKN mgN/l	PHOS mg/l	COD mg/l	TKN mgN/l	PHOS mg/l	NO3 mg/l	COD mg	TKN mgN	PHOS mg	NO3 mg	mg/l	mg/l	ml/g	mg	mg/l	mgO/ l/d	mg/l	
10-May-89	107	571	56.0	24.5	45	1.5	16.6	19.2	496	17	184	212				500	3	25	3345	
11-May-89	108	480		24.0	44		16.6	22.6	490		184	250	3088	2308	135	500		37	2984	8.1
12-May-89	109															500				
13-May-89	110	597	61.3	25.4	85	7.7	16.9	29.6	909	83	181	318	2968	2194	129	350		42		7.6
14-May-89	111	569		23.8	52	0.6	16.9	32.0	579	6	187	354	3032		124	500		31		7.6
15-May-89	112	556	56.8	24.5	129	2.5	16.1	31.2	1421	28	177	344	3068	2252	120	480		31		7.6
16-May-89	113	516	57.4	24.3	52	5.0		31.2	578	56		344	3068	2268	114	491		30		7.6
17-May-89	114	516	55.7	25.4	52	4.8	16.4	31.6	579	53	182	349	3154	2360	110	500	11	36		7.6
18-May-89	115	527	57.7	24.5	41	5.2	17.0	34.4	448	57	188	380	2996	2224	117	500		32		7.4
19-May-89	116	584	66.4	24.5	49	2.7	17.3	34.4	537	29	191	379	3106	2332	113	487		33		7.5
20-May-89	117	519	56.0	24.5	53	2.5	16.4	33.6	581	28	181	370	3298	2400	106	485		31		7.4
21-May-89	118	515	55.4	24.5	45	2.8	16.4	36.4	492	31	181	401				490				
22-May-89	119	487	55.2	24.5	61	3.4	17.3	35.8	665	37	189	391	3228	2380	103	441	20	40		7.4
23-May-89	120	475	52.1	23.7	57	2.0	17.0	39.6	627	22	188	437	3134	2338	106	495		40		7.4
24-May-89	121	512	55.2	24.8	49	1.1	16.4		538	12	181		3494	2636	100	495		30		7.3
AVERAGE 4		530	57.1	24.5	58	3.2	16.7	31.7	639	35	184	348	3136	2336	115	481		34	3164	7.5
25-May-89	122	544	74.5	25.5	69	4.3	15.8	32.8	765	48	175	362	3466	2636	106	500		40		7.4
26-May-89	123	397	51.8	24.1	45	13.7	15.8	23.8	496	151	175	263	3434	2562	112	494	5	32		
27-May-89	124	392	61.0	23.8	45	4.5	14.8	22.2	493	49	162	244				460				
28-May-89	125	347	50.1	22.8	45	3.6	15.1	23.8	497	40	167	263	3406	2508	108	500		29		7.4
29-May-89	126	380	50.1	22.4			16.5				182					470				
30-May-89	127	554	51.0	23.1	110	3.2	14.8	28.2	1215	36	163	312	3110	2272	107	500		29		7.5
31-May-89	128	525	53.5	22.8	77	3.1	14.1		849	34	155					461				
01-Jun-89	129	521	51.2	22.4	69	3.1	15.1	21.0	730	33	160	222	3170	2336	105	251		26		7.4
02-Jun-89	130	465	52.4	24.3	49	2.2	16.6	20.0	530	24	178	215	3006	2248	111	350	2	23		7.3
03-Jun-89	131	526	53.5	24.0	49	2.5	17.2	21.6	527	27	184	231	3382	2504	108	320		31		
04-Jun-89	132	456	51.8	24.0	49		16.3	30.4	534		177	330	3178	2320	105	395		19		7.3
05-Jun-89	133	509	46.8	24.3	41		16.3	38.4	442		177	417	3228	2390	103	401		33		7.4
06-Jun-89	134	476	53.2	23.7	102	3.9	16.6	32.0	1096	42	179	345	3058	2268	109	360		30		7.4
07-Jun-89	135	498	50.1	25.5	169	2.5	15.7	24.0	1816	27	169	258	2838	2088	106	360	24	29		7.5
08-Jun-89	136	526	54.9	24.9	62	3.1	16.3	24.8	669	33	177	269	3080	2236	108	400		30		7.6
09-Jun-89	137	368		26.1		3.1	15.7	20.6		33	170	224	3140	2362	106	400	8	26		
AVERAGE 5		468	53.7	24.0	70	4.1	15.8	26.0	761	44	172	282	3192	2364	107	414		29		7.4
10-Jun-89	138	584	49.6	26.7	78	5.5	16.0	18.0	839	59	172	193				345				
11-Jun-89	139	600	46.5	25.5	49	2.5	17.5		529	27	188		2812	2128	107	340		26		7.6
12-Jun-89	140	528	42.6	26.7	82	0.3	16.6	12.7	885	3	179	137	2812	2084	101	375	1	27		7.5
13-Jun-89	141	475	37.8	25.8	33	2.0	16.9	13.1	351	21	181	140	2692	1988	105	325		30		7.4
14-Jun-89	142	508	44.2	24.9	70	3.1	17.2	13.9	753	33	186	150	2702	1984	111	385		27		7.6
15-Jun-89	143	508	44.5	24.6	102	3.5	16.6	14.7	1096	37	178	158	2792	2064	107	325		23		7.6
16-Jun-89	144	541	43.6	25.2	78	2.4	16.3	13.5	836	26	175	145	2996	2166	106	350	0	26		
17-Jun-89	145	533	42.0	24.3	78	2.7	17.2	14.7	836	29	185	158	2846	2088	105	350		39		
18-Jun-89	146	508	44.0	24.9	70	3.6	16.9	12.9	745	39	181	138	2936	2108	102	325		29		
19-Jun-89	147	549	45.6	25.2	49	2.7	15.5	14.9	532	29	168	161	2560	1810	118	385	0	30		7.6
20-Jun-89	148	569	45.6	24.7	66	3.2	16.4	15.1	705	35	177	163	3104	2264	102	350				7.5
21-Jun-89	149	528	44.8	29.1	61	3.9	16.4	12.3	662	42	177	133	2810	2122	107	365		34		
22-Jun-89	150	425	43.1	26.3	49	3.6	15.8	14.1	539	40	174	155	2918	2252	109	470				7.6
23-Jun-89	151	442	43.7	23.8	37	2.4	15.5	16.6	396	26	167	179	2962	2258	148	360		41		
24-Jun-89	152	457		24.4	53	3.8	16.4	16.6	573	41	178	180	3150	2306	106	380		25		7.4
25-Jun-89	153	503	43.1	23.2	57	2.7	15.8	18.0	622	29	172	196				415				
26-Jun-89	154	482	60.5	23.2	45	3.6	15.8	20.9	482	39	170	224	2850	2078	111	340	7	24		
27-Jun-89	155	454	44.5		45	3.5	15.8	21.0	491	38	173	229	3034	2214	110	430		26		
28-Jun-89	156	503	49.3	24.6	45	5.5	16.5	18.1	491	60	180	197	3032	2268	110	430		24		
29-Jun-89	157	446	40.9	24.9			17.1	18.5			184	199	2954	2182	113	360		26		
AVERAGE 6		507	45.0	25.2	60	3.2	16.4	15.8	651	34	177	170	2887	2131	110	370		29		7.5
30-Jun-89	158	499	59.9	24.9	45	6.0	17.1	19.6	478	64	182	208	3046	2168	109	285	2	29		7.4
01-Jul-89	159	478	66.1	24.3			16.8	21.8			184	238	2782	2116	120	450		31		7.3

APPENDIX C: DATA MEASURED IN EXPERIMENTAL SYSTEM

DATE / STEADY STATE PERIOD No	DAY No.	MEASURED INFLUENT CONCENTRATIONS			MEASURED EFFLUENT CONCENTRATIONS				MASS IN EFFLUENT AFTER DILUTION				MLSS	MLVSS	DSVI	N ADDED	ANOX NO3	OUR	COD SLUDGE	pH
		COD mg/l	TKN mgN/l	PHOS mg/l	COD mg/l	TKN mgN/l	PHOS mg/l	NO3 mg/l	COD mg	TKN mgN	PHOS mg	NO3 mg	mg/l	mg/l	ml/g	mg	mg/l	mgO/l/d	mg/l	
02-Jul-89	160	538	60.5	24.9	49	4.1	16.5	24.2	526	44	178	262				390				
03-Jul-89	161	502	66.4	24.0	77	2.5	15.9	25.3	832	27	172	274	3000	2200	111	385	5	30		
04-Jul-89	162	478	58.2	24.0	57	2.7	15.6	24.4	617	29	169	265	2882	2176	116	415		31		7.4
05-Jul-89	163	522	61.2	25.2	45	2.0	15.6	25.6	481	21	168	276	2952	2208	113	375		28	2915	7.4
06-Jul-89	164	514	60.8	24.2	53	3.8	15.0	25.6	571	41	163	278	2928	2192	114	405		32	2915	
07-Jul-89	165	531	58.2	24.5	57	5.0	15.6	25.9	618	54	168	280	3156	2362	106	380	7	29	2984	7.5
08-Jul-89	166	548	62.2	24.8	86	4.5	16.2	25.9	925	48	174	279	3736	2560	89	365		29		
09-Jul-89	167	556		25.7	53		16.5		579		179					420				
10-Jul-89	168	556	56.3	26.0	49	3.4	16.5	23.1	532	36	179	250	3296	2408	101	400		28		
11-Jul-89	169	499	54.6	26.3	57	6.4	17.7	20.3	619	70	191	220	3246	2352	108	385		28		
12-Jul-89	170	524	54.0	26.9	53	3.6	17.8	20.8	574	39	193	225	3302	2408	110	380		31	3230	
13-Jul-89	171	522	55.4	27.3	45	3.9	18.1	19.4	482	42	194	208	3208	2334	105	340		33	3593	
14-Jul-89	172	543	54.0	29.1	61	2.5	18.4	20.8	662	27	199	225	3340	2422	109	385	0.1	39		7.4
15-Jul-89	173				45	3.4	18.1	19.2	480	36	194	205	3258	2336	107	320		28		
16-Jul-89	174	518	52.1	26.7	57		17.8	19.4	614		191	209				350		34		7.4
17-Jul-89	175	506	46.5	30.7	53	2.2	18.1	24.4	586	25	200	269	3156	2314	111	495		26		
18-Jul-89	176	514	48.2	25.8	45	3.8	17.5	22.4	473	40	185	236	4436	3326	82	250		27	3672	7.4
19-Jul-89	177	519	54.0	25.2	61	5.3	18.4	18.6	657	57	198	200	3736	2664	97	340	0.1	32		
AVERAGE 7		519	57.0	25.8	55	3.8	16.5	22.5	595	41	178	243	3262	2385		376		30		7.4
20-Jul-89	178	511	48.7	26.1	90	3.8	17.5	23.8	977	41	190	258	3444	2548	102	405		30		
21-Jul-89	179	511	48.4	25.8	65	1.8	17.5	23.6	687	19	184	248	3120	2228	108	225		29		
22-Jul-89	180	507	45.6	25.2												500				
23-Jul-89	181	507	46.5	23.8	45	2.4	18.0	16.2	497	26	199	179	3256	2368	104	500				
24-Jul-89	182	495	44.5	24.1	78		17.1	8.8	816		180	93	2896	2274	104	210		30		7.4
25-Jul-89	183	510	42.3	24.1	57	5.2	15.9	17.0	616	56	172	183	3044	2284	103	345		28	3089	
26-Jul-89	184	524	40.9	25.7		3.9	16.2	16.4		42	175	177	3020	2236	108	340	0.6	29		
27-Jul-89	185	524	45.4	24.7	89	3.2	15.5		962	35	167		3254	2312	100	330		30		7.4
28-Jul-89	186	536	46.2	29.3	77	3.5	14.3	23.0	831	38	154	247	3066	2180	106	330	7.4	31		
29-Jul-89	187	516	53.5	29.0	65	3.5	14.6	24.4	695	37	156	261	3232	2136	101	295		34		
30-Jul-89	188	475	42.8	29.3	57	3.8	14.6	25.4	611	41	157	273	3514	2384	92	330		33		
31-Jul-89	189	423	44.0	29.3	61	3.4	12.5	26.2	675	37	139	290	3366	2456	97	490	14.0	29		
01-Aug-89	190	451	42.6		45	3.6	13.4	26.4	483	39	145	285	3426	2372	95	350		31	3332	7.4
02-Aug-89	191	511	47.0	25.4									3574	2404	98	350				
03-Aug-89	192	515	46.2	25.4	61	4.2	12.8	21.2	656	45	138	229	3364	2324	97	340		29		
04-Aug-89	193	430	50.1	24.7		3.9	13.4	17.8		42	144	192	3422	2304	95	330		32		
AVERAGE 8		497	45.9	26.1	66	3.6	15.2	20.8	709	38	164	224	3267	2321	101	354		30	3211	7.4
05-Aug-89	194	539	51.0	25.1	65	5.3	14.1	19.0	696	57	151	204	3526	2548	99	310		33		7.4
06-Aug-89	195	527	46.2	25.4	65	4.2	14.4	18.8	700	45	155	203				350				
07-Aug-89	196	491	46.2	24.1	65	3.5	13.7	17.8	698	38	148	191	3338	2290	97	325	0.4	35		
08-Aug-89	197	519	45.6	24.7	89	3.1	13.1	17.6	962	33	141	190	3734	2476	97	340		31		
09-Aug-89	198	492		24.7	61	1.8	13.4	17.6	664	20	145	190	3450	2490	101	355		35		
10-Aug-89	199	496	42.0	25.4	90	3.9	13.1	17.4	966	42	141	187	3696	2630	101	310		32	3400	
11-Aug-89	200	519		24.7	79	3.9	13.5	17.4	851	42	145	188	3372	2488	105	345		36	3400	7.4
12-Aug-89	201	515	46.2	24.5	46	4.8	13.5	17.4	491	51	145	187				325		36		
13-Aug-89	202	498	47.9	23.3	66	4.2	13.8	17.0	719	45	149	184				360				
14-Aug-89	203	536	54.0	24.3	62	0.6	13.5	17.8	671	6	145	192	3756	2570	104	340		36		
15-Aug-89	204		43.1	25.2		2.2	13.8	18.6		24	150	202	3568	2488	112	385	0.8	39	3114	
16-Aug-89	205	536	49.3	24.5	91	3.2	14.1	16.8	988	35	152	182	3648	2702	110	360		36		
17-Aug-89	206	507	42.0	24.5	91	10.9	15.3	10.6	991	118	166	115	3202	1976	101	375				
18-Aug-89	207	511	42.8	24.2	66	3.5	14.1	17.2	710	37	151	184	3394	2242	118	295		33		
19-Aug-89	208	455	45.9	25.2	78		13.5	16.8	838		145	181	3512	2326		335		36		
20-Aug-89	209	504	46.5	27.6	74	8.5	13.8	20.4	801	93	150	222				380				
21-Aug-89	210	493	46.2	25.7		4.3	14.0	17.6		47	152	191	3592	2496	106	365	0.8	38		7.5
22-Aug-89	211		48.2	26.7	66	0.3	14.6	17.8	706	3	157	191	3724	2498	107	315				
23-Aug-89	212	473	49.0	24.8	86	0.6	13.7	18.2	935	6	148	197	3618	2464	105	365		36		
24-Aug-89	213	510	51.8	26.7	58	4.2	14.0	20.0	617	45	150	214	3542	2416	102	310				7.4
25-Aug-89	214	498		24.5	62	3.9	14.0	20.4	665	42	151	220	3346	2476	108	340	0.6	38		
26-Aug-89	215	518	53.2	24.5	82	4.2	13.7	20.8	880	45	146	223	3750	2388	101	300				

APPENDIX C: DATA MEASURED IN EXPERIMENTAL SYSTEM

DATE / STEADY STATE PERIOD No	DAY No.	MEASURED INFLUENT CONCENTRATIONS			MEASURED EFFLUENT CONCENTRATIONS				MASS IN EFFLUENT AFTER DILUTION				MLSS	MLVSS	DSVI	N ADDED	ANOX NO3	OUR	COD SLUDGE	pH
		COD mg/l	TKN mgN/l	PHOS mg/l	COD mg/l	TKN mgN/l	PHOS mg/l	NO3 mg/l	COD mg	TKN mgN	PHOS mg	NO3 mg	mg/l	mg/l	ml/g	mg	mg/l	mgO/l/d	mg/l	
27-Aug-89	216	493	51.0	24.5	58	0.7	13.4	20.6	619	8	144	221	3812	2552	97	325		41		
28-Aug-89	217	493	50.1	25.1	74	3.6	13.0	20.6	802	40	142	224	3540	2500	102	390				
29-Aug-89	218	500	52.4	23.2	82	2.9	13.0	21.6	875	31	139	231	3658	2458	104	290		40		
30-Aug-89	219	504	49.6	25.4	70	3.8	12.9	20.8	759	41	141	227	3860	2516	93	400		33		
31-Aug-89	220	512	52.1	23.2	86	4.8	13.0	21.4	933	52	141	232	3590	2402	100	375		39		
AVERAGE 9		505	48.0	24.9	72	3.7	13.7	18.4	781	40	148	199	3575	2452	103	343	0.7	36	3304	7.4
01-Sep-89	221	492	54.0	24.1	74	3.8	12.6	24.0	807	41	138	263	3694	2440	92	425		46		
02-Sep-89	222	384	44.5	24.1		4.3	12.9	25.2		47	140	274				380				
03-Sep-89	223	504	41.7	26.8		3.2	13.5	20.4		35	149	224				450				
04-Sep-89	224	430	41.7		66	4.1	13.2	17.4	716	44	144	190	3882	2522	87	415		36		
05-Sep-89	225	483	36.1	23.5	102	5.5	12.9	18.8	1132	60	143	208	3700	2458	92	475		29		
06-Sep-89	226	504	41.7	24.7	45	3.2	12.9	20.6	495	35	142	226	3834	2612	83	440		33		
07-Sep-89	227	500	38.6	24.7	53	1.1	13.2	21.4	584	12	145	235	3578	2432	89	430		34		
08-Sep-89	228	545	66.6	24.1	66	9.8	12.6	22.2	709	106	136	240	3756	2408	93	360		33		7.5
09-Sep-89	229	459	41.4	24.1	45	3.6	12.1	20.2	492	40	132	222	3574	2322	93	435		35		
10-Sep-89	230	461	39.2	23.5	57	3.9	12.1	16.2	620	43	132	177	3380	2286		405		33		
11-Sep-89	231	461	39.2		57	3.9	12.4	18.8	625	43	136	206	4128	2748	82	430		35		
12-Sep-89	232	441	44.8	23.9	57	13.2	14.7	11.0	628	145	161	121	3860	2594	85	445		40		
AVERAGE 10		472	44.1	24.3	62	5.0	12.9	19.7	681	54	141	215	3739	2482	88	424		36		7.5
~~13-Sep-89~~	~~233~~	~~457~~	~~44.0~~	~~24.5~~	~~67~~	~~7.1~~	~~14.7~~	~~17.2~~	~~518~~	~~80~~	~~164~~	~~192~~	3840	2484	83	440		36	3264	
14-Sep-89	234	481	43.7	26.8	73	6.3	14.0	20.4	635	70	156	227	3834	2532	81	420		26		7.5
15-Sep-89	235	481	45.9	32.7	78	3.2	19.3	22.0	663	36	214	245	3896	2608	82	415		29		7.5
16-Sep-89	236	461	40.3	39.6	73	1.1	24.2	21.8	575	12	267	241	3720	2356	86	380		32		
17-Sep-89	237	461	42.6	14.4	118	17.8	17.0	9.8	853	195	187	108	3092	1984	84	350		33		
18-Sep-89	238	405	38.1	36.3	65	8.8	20.9	15.4	574	98	233	172	3528	2452	91	430		31	3019	
19-Sep-89	239	457	36.7	14.4	73	6.9	16.6	21.8	713	77	186	245	3620	2472	83	475				
20-Sep-89	240	453	40.6	35.9	81	3.5	13.4	26.2	767	39	151	294	3642	2570	88	460		28		7.7
AVERAGE 11		457	41.5	28.1	77	6.8	17.5	19.3	662	76	195	216	3647	2432	85	421		31	3142	7.6
21-Sep-89	241	457	52.1	10.6	73	2.9	14.4	33.2	630	33	160	370				420	19.8	29	3279	
22-Sep-89	242	441	51.2	35.3	57	5.0	13.4	32.4	639	57	152	365	3556	2458	90	490	8.3	28	2915	
23-Sep-89	243	467	52.4	13.4	77	5.0	14.4	31.6	849	55	158	348				350				7.4
24-Sep-89	244	474		13.4	65	6.7	14.7	32.4	729	76	165	365	3174	2092	88	480				
25-Sep-89	245	433	54.3	13.4	53	2.2	15.9	39.6	593	25	179	446	3480	2354	86	480	14.0	33	3157	
26-Sep-89	246	488	50.7	34.4	53		14.4	34.6	592		161	388	3536	2440	85	455	15.2	33		7.3
27-Sep-89	247	483	36.1	12.9		4.1	16.9	36.0		46	189	404	3108	2082	97	455		24		
28-Sep-89	248	496	41.7	36.3	77	3.5	14.7	23.2	870	39	166	261	3260	2284	92	485		26		
29-Sep-89	249	548	42.3	10.3	89	1.0	16.0	22.6	1007	11	180	255	3568	2414	95	490				7.4
30-Sep-89	250	471	37.5	34.7			14.4	19.8			162	223	3634	2430	85	490				
01-Oct-89	251	496	40.3	11.2	85	5.6	15.0	21.8	963	63	169	246	3692	3382	89	490				
02-Oct-89	252	496	40.9	34.1	89	4.3	13.4	21.0	1007	48	151	236	3344	2218	90	480		21		
03-Oct-89	253	504	44.5	11.6	73	5.9	15.3	16.6	825	66	172	187	3612	2482	89	485		24		7.6
04-Oct-89	254	491	37.5	36.6	69	4.1	13.4	15.4	776	46	151	173	3474	2446	89	475		25	3326	
05-Oct-89	255	462	37.8	10.0	73	2.9	15.0	15.0	816	33	168	168	3412	2426	88	440		25		7.5
06-Oct-89	256	491	40.0	34.1	89	3.8	14.7	15.4	1005	43	165	173	3412	2358	91	480		24	3164	
07-Oct-89	257	438	38.1	10.0			15.3	18.6			172	209	3412	2376	91	455		30		
08-Oct-89	258	479	38.9	35.2	61	4.1	14.6	20.8	686	46	164	234	3454	2396	97	485				
09-Oct-89	259	475	37.2	11.0	65	2.7	15.6	20.8	728	30	175	233	3198	2220	97	460		26		7.5
10-Oct-89	260	531	40.9	39.0	73	3.1	15.9	20.6	818	34	178	231				450				
11-Oct-89	261				69	3.5	16.9	20.4	778	40	190	230	3282	2324	88	495		27		
12-Oct-89	262	487	42.8	41.9	61	4.3	16.2	19.2	678	48	181	214	3244	2336	89	425		25		
AVERAGE 12		490	39.8	24.6	75	3.8	15.2	20.5	843	42	171	230	3407	2412	91	471		25	3245	7.5
13-Oct-89	263	557		13.0	69	4.1	16.9	19.0	774	46	189	213	3442	2502	84	460	3.1	24		7.7
14-Oct-89	264	519		11.7	65	4.1	8.4	19.4	723	45	94	217	3106	2190	93	430		24		

APPENDIX C: DATA MEASURED IN EXPERIMENTAL SYSTEM

DATE / STEADY STATE PERIOD No	DAY No.	MEASURED INFLUENT CONCENTRATIONS			MEASURED EFFLUENT CONCENTRATIONS				MASS IN EFFLUENT AFTER DILUTION				MLSS	MLVSS	DSVI	N ADDED	ANOX NO3	OUR	COD SLUDGE	pH
		COD mg/l	TKN mgN/l	PHOS mg/l	COD mg/l	TKN mgN/l	PHOS mg/l	NO3 mg/l	COD mg	TKN mgN	PHOS mg	NO3 mg	mg/l	mg/l	ml/g	mg	mg/l	mgO/ l/d	mg/l	
15-Oct-89	265	555	63.6	11.7	73	2.7	5.8	20.0	819	30	65	225	3620	2628	86	470		25		
16-Oct-89	266	538	44.2	11.3	85	2.0	5.2	20.4	959	22	58	230	3440	2442	84	490		25		7.7
17-Oct-89	267	542	44.2	11.7	81	2.1	4.5	24.6	915	24	51	278				500				
18-Oct-89	268	514	39.2	10.7	57	2.9	4.0	23.6	635	33	45	264	2886	2060	92	450		24		
19-Oct-89	269	530	43.7	11.0	57	1.4	3.4	25.0	640	16	38	280	2814	2048	93	455		25		7.7
20-Oct-89	270	543	42.6	11.9	65	2.0	3.7	27.2	738	22	42	307	3324	2424	87	500		30		
21-Oct-89	271	481	44.2	11.0	53	5.3	3.4	20.0	597	60	38	225	3254	2382	89	475		31		
22-Oct-89	272	551	40.3	10.7	69	6.6	3.7	25.0	783	74	42	282	3466	2546	83	495		32		7.6
23-Oct-89	273	575	44.2	11.0	33	6.0		24.6	369	68		278	3208	2320	90	500		28		
24-Oct-89	274	530	45.4	11.0	139	4.1		18.2	1561	46		205	3434	2450	85	475		24		
25-Oct-89	275	522		11.0	253	6.6	6.2	19.0	2831	74	69	213	3342	2500	86	445	6.8			
26-Oct-89	276	469	36.7	10.1	57	3.8	3.4	9.2	645	43	38	104	3532	2672	88	500		26		
27-Oct-89	277	522	37.8	10.4	65	4.1	3.4		732	46	38		3382	2502	85	455	1.2			7.5
28-Oct-89	278	530		10.1	73	3.4	3.7	10.6	825	38	42	119	3484	2536	83	465		22		
29-Oct-89	279	571	38.6	11.3	86	3.1	4.2	18.2	968	35	47	206				500				7.6
30-Oct-89	280	551	35.6	10.8	90	3.9	4.5	15.2	1014	44	50	172	2816	2098	95	500	7.4	25		
31-Oct-89	281	555	37.0	11.7	57	2.8	4.5	11.2	635	31	50	124	2688	2004	91	405	3.0	27		7.7
01-Nov-89	282	514	36.1	11.0	86	4.8	4.6	2.6	964	54	52	29	2734	2052	93	475	12.8	30	3264	7.6
02-Nov-89	283	470	45.1	11.3	74	5.9	4.5	15.0	829	66	50	169	3054	2242	91	485		20		
03-Nov-89	284	503	35.8	11.3	53	4.3	5.1	15.2	600	49	57	172	2892	2122	92	500		24		
AVERAGE 13		521	37.8	10.9	89	4.3	4.4	12.9	1004	48	49	145	3103	2303	89	473		25	3264	7.6
04-Nov-89	285	442	36.1	8.7	65	4.1	4.2	22.2	738	46	47	251				500				
05-Nov-89	286	600	34.7	24.8	73	4.6	6.3	21.6	830	52	71	244				500				
06-Nov-89	287	506	38.4	10.7	49	2.0	8.1	22.6	570	23	94	263	3732	2732	89	500		23		7.7
07-Nov-89	288	437	38.1	8.5		8.4	5.4	25.8		98	63	301	3684	2748	88	500	16.6	22		7.6
08-Nov-89	289	438	35.8	8.5	95	7.7	4.0	26.0	1105	90	47	303	3470	2504	90	495		26		
09-Nov-89	290	466	41.4	8.8	107	4.3	3.3	18.4	1238	50	38	212	3680	2792	82	440		23	3385	7.4
10-Nov-89	291	433	42.0	8.6	110	7.6	3.0		1286	88	34		3484	2450	96	500		23		
11-Nov-89	292	421	40.0	8.8	74	6.3	2.5	18.6	855	73	29	214	3262	2354	100	430	14.4	24		
12-Nov-89	293			8.8		6.2	2.4	19.8		71	27	228				425				
13-Nov-89	294	458	40.3	9.4	83	5.7	2.4	20.4	942	65	27	233	3532	2616	94	380		20		7.4
14-Nov-89	295	439	38.9	9.3	99		2.7	21.2	1153		31	247	3266	2390	95	495				
15-Nov-89	296	466	56.6	9.3	140	4.1	2.5	16.8	1587	46	28	190	6416	2506	98	330		24		
AVERAGE 14		464	40.2	10.3	90	5.5	3.9	21.2	1030	64	45	244	3836	2566	92	458		23	3385	7.5
16-Nov-89	297	499	56.0	9.6	86	3.8	2.2	11.8	968	43	25	133	3576	2722	93	315		24		
17-Nov-89	298	480	55.2	9.7			2.0				24		4618	3392	70	450		24		7.4
18-Nov-89	299	443		7.6			2.0				23		3544	2658	94	415		22		
19-Nov-89	300		50.7	7.2		5.2	1.9			59	21		3528	2458	91	335				
20-Nov-89	301	566		7.2	78		2.0		868		22		3154	2290	99	265	5.0	30		7.4
21-Nov-89	302	474	44.8	7.2	70	25.8	2.0		792	293	23		3722	2704	102	370		31		
22-Nov-89	303	474	45.6	7.2	61	8.8	1.9		701	101	22		3914	2898	99	390	20.0	30		
23-Nov-89	304	417	48.4	7.4	65	4.3	2.3		740	49	26		3786	2754	106	325	24.0	29		7.4
24-Nov-89	305	478		7.1	61		1.6		700		18		3712	2688	108	385				
AVERAGE 15		479	50.1	7.8	70	9.6	2.0	11.8	795	109	23	133	3728	2729	96	361		27		7.4
25-Nov-89	306	474	50.7													330				7.4
26-Nov-89	307				58		1.8		649				3638	2624	104	315				
27-Nov-89	308	497	56.6		66		2.2		749				3716	2680	102	375				
28-Nov-89	309	484	50.7		82		2.1		955				3926	2820	108	495				
29-Nov-89	310															500				
30-Nov-89	311															500				

APPENDIX D:
DEWATERABILITY TESTS

APPENDIX D - DEWATERABILITY TESTS

VARIATION IN SRF AND CST VALUES OF ACTIVATED SLUDGE FROM ZEEKOEIVLEI SEWAGE WORKS WHEN MIXED DIRECTLY WITH ALUM SLUDGE

% ALUM by mass	DSVI	TOTAL SUSPENDED SOLIDS	SRF x10^12	CST
	ml/g	kg/m^3	kg/m	sec
0	166	2.535	8.2	6.2
3.73	167	2.544	12.6	6.6
7.18	181	2.552	19.2	7.7
10.4	190	2.56	29.6	8.5
13.4	189	2.568	34.7	11
16.21	194	2.575	57.3	10.6
18.84	167	2.581	54.4	12.1
21.31	180	2.588	46.8	13.5
23.63	193	2.593	57.5	15.3
25.83	205	2.599	68.8	17.9
100	309	2.802	54.4	23.3

VARIATION IN SRF AND CST VALUES OF PRIMARY SLUDGE FROM ZEEKOEIVLEI WORKS WHEN MIXED DIRECTLY WITH ALUM SLUDGE

'% ALUM by mass	TOTAL SUSPENDED SOLIDS	SRF x10^12	CST
	kg/m^3	kg/m	secs.
0	17.932	187.5	91
6.02	13.327	59.5	46.6
11.86	10.708	43.6	60.4
19.55	8.491	42.8	49.6
27.2	7.038	47.9	46.4
35.9	5.892	48	43.5
45.12	5.027	60.1	35.7
57.37	4.207	64.6	36
69.16	3.654	71.4	30
83.56	3.117	62.8	26.3
100	2.681	68.7	23.3

APPENDIX D - DEWATERABILITY TESTS

VARIATION IN SRF AND CST VALUES OF RETURN ACTIVATED SLUDGE FROM ZEEKOEIVLEI SEWAGE WORKS WHEN MIXED DIRECTLY WITH ALUM SLUDGE.

% ALUM BY MASS	DSVI ml/g	TOTAL SOLIDS CONC. mg/l	SRF m/kg	CST sec
0	157	5.391	8.4	6.6
6.34	198	5.139	36.8	7.8
14.01	212	4.864	60.3	14.5
21.99	228	4.607	46	20.8
28.71	219	4.411	78.9	31.4
39.68	267	4.125	92.7	29.1
49.68	295	3.895	87.7	29.6
60.06	353	3.681	96.7	33.1
71.73	548	3.467	85.8	30.7
84.94	594	3.254	69	27.4
100	866	3.04	67.3	25.5

VARIATION IN SRF AND CST VALUES OF ANAEROBICALLY DIGESTED SLUDGE FROM ZEEKOEIVLEI SEWAGE WORKS WHEN DIRECTLY MIXED WITH ALUM SLUDGE

% ALUM BY MASS	TOTAL SUSPENDED SOLIDS kg/m^3	SRF m/kg x10^12	CST sec
0	17.21	772.62	575
2.72	15.493	473.1	450
6.54	13.44	431.33	360
12.2	11.251	448.09	285
18.31	9.61	232.59	240
24.6	8.33	353.02	200
33.2	7.056	225.61	150
42.76	6.034	285.36	130
52.84	5.232	231.27	100
70.82	4.228	158.9	75
100	3.225	66.52	30

APPENDIX D - DEWATERABILITY TESTS

VARIATION IN SRF VALUES OF ANAEROBICALLY DIGESTED SLUDGE FROM ZEEKOEIVLEI SEWAGE WORKS WITH DIRECT ALUM ADDITION THE SOLIDS CONCENTRATION WAS KEPT CONSTANT WITH VARYING ALUM DOSES

% ALUM BY MASS	TOTAL SUSPENDED SOLIDS kg/m^3	SRF m/kg x10^12
0	8.033	1054.9
11.16	8.04	496.1
18.44	7.98	492
30.54	7.96	324.8
39.75	7.93	270.7
48.52	7.42	243.5
60.12	6.63	173.6
69.34	6.26	140.5
79.03	5.39	112
100	3.255	65.9

VARIATION IN SRF VALUES OF ANAEROBICALLY DIGESTED SLUDGE FROM ATHLONE SEWAGE WORKS WHEN DIRECTLY MIXED WITH ALUM SLUDGE THE SOLIDS CONCENTRATION WAS KEPT CONSTANT WITH VARYING ALUM SLUDGE DOSES

% ALUM BY MASS	TOTAL SUSPENDED SOLIDS kg/m^3	SRF m/kg x10^12
0	4.445	32.1
13.04	4.543	28.5
23.07	4.577	32.1
34.42	4.675	40.5
42.85	4.714	43.5
54.53	4.789	56.6
64.28	4.763	80.6
72.4	4.957	39.7
81.81	4.768	51.1
91.83	4.657	49.3
100	2.66	63.4

APPENDIX D - DEWATERABILITY TESTS

VARIATION IN SRF VALUES OF RETURN ACTIVATED SLUDGE
FROM ATHLONE SEWAGE WORKS WHEN MIXED DIRECTLY WITH ALUM SLUDGE
THE SOLIDS CONCENTRATION WAS KEPT CONSTANT WITH VARYING
ALUM DOSES

% ALUM BY MASS	TOTAL SUSPENDED SOLIDS kg/m^3	SRF m/kg x10^12
0	5.486	17.3
13.3	5.606	46.6
24.2	5.679	80.3
33.9	5.778	89.4
45	5.85	89.3
56.1	5.982	74.1
65.2	6.154	82
75.4	5.935	80.2
83.7	5.573	66.5
92.1	4.98	66
100	4.953	51.3

APPENDIX D - DEWATERABILITY TESTS

COMPARISON OF SRF VALUES IN LABORATORY SYSTEMS

CONTROL SYSTEM NO ALUM SLUDGE ADDED			EXPERIMENTAL SYSTEM ALUM SLUDGE ADDED DAILY		
TEST NO	TOTAL SUSPENDED SOLIDS kg/m^3	SRF m/kg x10^12	TOTAL SUSPENDED SOLIDS kg/m^3	SRF m/kg x10^12
1	2.122	12.56	3.612	11.59
2	1.752	38.4	3.412	25.67
3	1.804	14.77	3.344	14.12
4	4.784	13.17	5.671	10.73
5	4.708	11.81	4.067	10.24

APPENDIX E:
STIRRED JAR BATCH TEST DATA

APPENDIX E

STIRRED JAR BATCH TEST NUMBER 1

pH: 6.8
ISS CONC. OF ALUM SLUDGE: 1384 mg/l
INITIAL VOLUME: 490 ml
VOLUME ALUM DOSED: 40 ml

MASS ALUM ISS DOSED: 55.36 mgISS
EQUIV. Al MASS DOSED 29.12 mgAl
P initial/ISS added: 0.467

TIME hours	TIME days	P CONC. mgP/l	P MASS mgP	MASS P REMOVED mgP	mgP rem/ mgISS add mgP/mgISS	mgP rem/ mgAl add mgP/mgAl	% P remaining
0.00	0.0	48.75	25.84	0	0.000	0.000	100
0.25	0.0	41.24	21.86	3.98	0.072	0.137	85
10.50	0.4	38.28	20.29	5.55	0.100	0.191	79
23.50	1.0	37.98	20.13	5.71	0.103	0.196	78
33.17	1.4	35.11	18.61	7.23	0.131	0.248	72
47.00	2.0	32.65	17.30	8.53	0.154	0.293	67
70.50	2.9	31.45	16.67	9.17	0.166	0.315	65
94.67	3.9	29.65	15.71	10.12	0.183	0.348	61
120.67	5.0	26.03	13.80	12.04	0.218	0.414	53
144.33	6.0	29.36	15.56	10.28	0.186	0.353	60
166.50	6.9	25.73	13.64	12.20	0.220	0.419	53
191.08	8.0	24.83	13.16	12.68	0.229	0.435	51
214.50	8.9	22.07	11.70	14.14	0.255	0.486	45
238.67	9.9	20.76	11.00	14.83	0.268	0.509	43
262.58	10.9	19.21	10.18	15.66	0.283	0.538	39
288.83	12.0	16.50	8.75	17.09	0.309	0.587	34
310.17	12.9	16.50	8.75	17.09	0.309	0.587	34
334.50	13.9	16.19	8.58	17.26	0.312	0.593	33
358.33	14.9	12.22	6.48	19.36	0.350	0.665	25
383.25	16.0	10.34	5.48	20.36	0.368	0.699	21
406.92	17.0	9.39	4.98	20.86	0.377	0.716	19
430.33	17.9	8.48	4.49	21.34	0.386	0.733	17
502.50	20.9	4.37	2.32	23.52	0.425	0.808	9
550.58	22.9	1.57	0.83	25.01	0.452	0.859	3
598.33	24.9	1.24	0.66	25.18	0.455	0.865	3

APPENDIX E

STIRRED JAR BATCH TEST NUMBER 2

pH: 6.8
ISS CONC. OF ALUM SLUDGE: 1384 mg/l
INITIAL VOLUME: 490 ml
VOLUME ALUM DOSED: 20 ml

MASS ALUM ISS DOSED: 27.68 mgISS
EQUIV. Al MASS DOSED 14.56 mgAl
P initial/ISS added: 0.917

TIME hours	TIME days	P CONC. mgP/l	P MASS mgP	MASS P REMOVED mgP	mgP rem/ mgISS add mgP/mgISS	mgP rem/ mgAl add mgP/mgAl	% P remaining
0.00	0.0	49.77	25.38	0	0.000	0.000	100
0.17	0.0	45.55	23.23	2.15	0.078	0.148	92
10.33	0.4	43.75	22.31	3.07	0.111	0.211	88
23.17	1.0	42.84	21.85	3.53	0.128	0.243	86
32.92	1.4	41.89	21.36	4.02	0.145	0.276	84
47.08	2.0	40.35	20.58	4.80	0.174	0.330	81
70.33	2.9	40.17	20.49	4.90	0.177	0.336	81
94.42	3.9	39.13	19.96	5.43	0.196	0.373	79
120.42	5.0	36.62	18.68	6.71	0.242	0.461	74
144.08	6.0	35.71	18.21	7.17	0.259	0.492	72
166.25	6.9	35.11	17.91	7.48	0.270	0.514	71
190.83	8.0	34.33	17.51	7.87	0.284	0.541	69
214.25	8.9	33.41	17.04	8.34	0.301	0.573	67
238.50	9.9	32.22	16.43	8.95	0.323	0.615	65
262.42	10.9	29.12	14.85	10.53	0.380	0.723	59
288.67	12.0	29.58	15.09	10.30	0.372	0.707	59
309.92	12.9	29.27	14.93	10.46	0.378	0.718	59
334.33	13.9	31.45	16.04	9.34	0.338	0.642	63
358.08	14.9	25.38	12.94	12.44	0.449	0.854	51
383.08	16.0	25.38	12.94	12.44	0.449	0.854	51
406.83	17.0	22.72	11.59	13.80	0.498	0.948	46
430.08	17.9	21.81	11.12	14.26	0.515	0.979	44
502.33	20.9	12.80	6.53	18.85	0.681	1.295	26
550.42	22.9	7.87	4.01	21.37	0.772	1.468	16
598.17	24.9	4.03	2.06	23.33	0.843	1.602	8

APPENDIX E

STIRRED JAR BATCH TEST NUMBER 3

pH: 6.8
ISS CONC. OF ALUM SLUDGE: 1384 mg/l
INITIAL VOLUME: 490 ml
VOLUME ALUM DOSED: 10 ml

MASS ALUM ISS DOSED: 13.84 mgISS
EQUIV. Al MASS DOSED 7.28 mgAl
P initial/ISS added: 1.834

TIME hours	TIME days	P CONC. mgP/l	P MASS mgP	MASS P REMOVED mgP	mgP rem/ mgISS add mgP/mgISS	mgP rem/ mgAl add mgP/mgAl	% P remaining
0.00	0.0	50.77	25.39	0	0.000	0.000	100
0.17	0.0	48.63	24.32	1.07	0.077	0.147	96
9.50	0.4	46.79	23.40	1.99	0.144	0.273	92
23.33	1.0	46.18	23.09	2.30	0.166	0.315	91
32.83	1.4	44.35	22.18	3.21	0.232	0.441	87
47.00	2.0	43.43	21.72	3.67	0.265	0.504	86
70.50	2.9	43.29	21.65	3.74	0.270	0.514	85
94.33	3.9	41.57	20.79	4.60	0.332	0.632	82
120.33	5.0	40.86	20.43	4.96	0.358	0.681	80
144.00	6.0	39.95	19.98	5.41	0.391	0.743	79
166.17	6.9	39.65	19.83	5.56	0.402	0.764	78
190.83	8.0	38.93	19.47	5.92	0.428	0.813	77
214.17	8.9	38.31	19.16	6.23	0.450	0.856	75
238.42	9.9	36.87	18.44	6.95	0.502	0.955	73
262.33	10.9	36.56	18.28	7.11	0.513	0.976	72
288.58	12.0	35.50	17.75	7.64	0.552	1.049	70
309.92	12.9	34.56	17.28	8.11	0.586	1.113	68
334.25	13.9	35.81	17.91	7.48	0.540	1.027	71
358.00	14.9	32.28	16.14	9.25	0.668	1.270	64
383.08	16.0	32.28	16.14	9.25	0.668	1.270	64
406.83	17.0	30.60	15.30	10.09	0.729	1.385	60
430.08	17.9	30.60	15.30	10.09	0.729	1.385	60
502.33	20.9	29.35	14.68	10.71	0.774	1.471	58
550.42	22.9	28.65	14.33	11.06	0.799	1.519	56
598.17	24.9	27.92	13.96	11.43	0.826	1.569	55

APPENDIX E

STIRRED JAR BATCH TEST NUMBER 4

pH: 7
ISS CONC. OF ALUM SLUDGE: 1384 mg/l
INITIAL VOLUME: 490 ml
VOLUME ALUM DOSED: 40 ml

MASS ALUM ISS DOSED: 55.36 mgISS
EQUIV. Al MASS DOSED 29.12 mgAl
P initial/ISS added: 0.436

TIME hours	TIME days	P CONC. mgP/l	P MASS mgP	MASS P REMOVED mgP	mgP rem/ mgISS add mgP/mgISS	mgP rem/ mgAl add mgP/mgAl	% P remaining
0.00	0.0	45.51	24.12	0	0.000	0.000	100
0.08	0.0	40.47	21.45	2.67	0.048	0.092	89
22.17	0.9	36.28	19.23	4.89	0.088	0.168	80
44.50	1.9	32.49	17.22	6.90	0.125	0.237	71
73.17	3.0	32.79	17.38	6.74	0.122	0.232	72
94.00	3.9	31.52	16.71	7.41	0.134	0.255	69
118.00	4.9	33.05	17.52	6.60	0.119	0.227	73
141.92	5.9	33.48	17.74	6.38	0.115	0.219	74
166.17	6.9	31.33	16.60	7.52	0.136	0.258	69
189.92	7.9	30.15	15.98	8.14	0.147	0.280	66
213.33	8.9	30.75	16.30	7.82	0.141	0.269	68
240.35	10.0	28.68	15.20	8.92	0.161	0.306	63
262.17	10.9	28.39	15.05	9.07	0.164	0.312	62
286.00	11.9	30.24	16.03	8.09	0.146	0.278	66
309.83	12.9	28.07	14.88	9.24	0.167	0.317	62
333.92	13.9	27.72	14.69	9.43	0.170	0.324	61
358.33	14.9	26.79	14.20	9.92	0.179	0.341	59
380.42	15.9	25.78	13.66	10.46	0.189	0.359	57
409.50	17.1	28.23	14.96	9.16	0.165	0.315	62
429.92	17.9	25.78	13.66	10.46	0.189	0.359	57
454.08	18.9	26.45	14.02	10.10	0.182	0.347	58
478.08	19.9	25.87	13.71	10.41	0.188	0.357	57

APPENDIX E

STIRRED JAR BATCH TEST NUMBER 5

pH: 7
ISS CONC. OF ALUM SLUDGE: 1384 mg/l
INITIAL VOLUME: 490 ml
VOLUME ALUM DOSED: 25 ml

MASS ALUM ISS DOSED: 34.6 mgISS
EQUIV. Al MASS DOSED 18.20 mgAl
P initial/ISS added: 0.701

TIME hours	TIME days	P CONC. mgP/l	P MASS mgP	MASS P REMOVED mgP	mgP rem/ mgISS add mgP/mgISS	mgP rem/ mgAl add mgP/mgAl	% P remaining
0.00	0.0	47.12	24.27	0	0.000	0.000	100
0.08	0.0	45.00	23.18	1.09	0.032	0.060	96
22.17	0.9	40.85	21.04	3.23	0.093	0.177	87
44.42	1.9	38.80	19.98	4.28	0.124	0.235	82
73.17	3.0	38.50	19.83	4.44	0.128	0.244	82
94.00	3.9	37.95	19.54	4.72	0.136	0.259	81
118.00	4.9	38.26	19.70	4.56	0.132	0.251	81
141.92	5.9	37.74	19.44	4.83	0.140	0.265	80
166.72	6.9	36.81	18.96	5.31	0.153	0.292	78
189.92	7.9	37.15	19.13	5.13	0.148	0.282	79
213.33	8.9	37.85	19.49	4.77	0.138	0.262	80
240.17	10.0	36.66	18.88	5.39	0.156	0.296	78
262.17	10.9	36.37	18.73	5.54	0.160	0.304	77
286.00	11.9	36.11	18.60	5.67	0.164	0.312	77
309.83	12.9	38.17	19.66	4.61	0.133	0.253	81
333.92	13.9	35.11	18.08	6.19	0.179	0.340	75
358.33	14.9	34.18	17.60	6.66	0.193	0.366	73
380.42	15.9	34.37	17.70	6.57	0.190	0.361	73
409.50	17.1	33.76	17.39	6.88	0.199	0.378	72
429.92	17.9	33.76	17.39	6.88	0.199	0.378	72
454.08	18.9	33.75	17.38	6.89	0.199	0.378	72
478.08	19.9	33.31	17.15	7.11	0.206	0.391	71

APPENDIX E

STIRRED JAR BATCH TEST NUMBER 6

pH: 7
ISS CONC. OF ALUM SLUDGE: 1384 mg/l
INITIAL VOLUME: 490 ml
VOLUME ALUM DOSED: 15 ml

MASS ALUM ISS DOSED: 20.76 mgISS
EQUIV. Al MASS DOSED 10.92 mgAl
P initial/ISS added: 1.169

TIME hours	TIME days	P CONC. mgP/l	P MASS mgP	MASS P REMOVED mgP	mgP rem/ mgISS add mgP/mgISS	mgP rem/ mgAl add mgP/mgAl	% P remaining
0.00	0.0	48.05	24.27	0	0.000	0.000	100
0.08	0.0	46.51	23.49	0.78	0.037	0.071	97
22.17	0.9	44.51	22.48	1.79	0.086	0.164	93
44.42	1.9	42.41	21.42	2.85	0.137	0.261	88
73.17	3.0	41.21	20.81	3.45	0.166	0.316	86
94.00	3.9	41.93	21.17	3.09	0.149	0.283	87
118.00	4.9	40.40	20.40	3.86	0.186	0.354	84
141.92	5.9	39.57	19.98	4.28	0.206	0.392	82
166.72	6.9	40.15	20.28	3.99	0.192	0.365	84
189.92	7.9	38.98	19.68	4.58	0.221	0.419	81
213.33	8.9	38.73	19.56	4.71	0.227	0.431	81
240.17	10.0	37.26	18.82	5.45	0.262	0.499	78
262.17	10.9	36.37	18.37	5.90	0.284	0.540	76
286.00	11.9	36.11	18.24	6.03	0.290	0.552	75
309.83	12.9	35.96	18.16	6.11	0.294	0.559	75
333.92	13.9	33.57	16.95	7.31	0.352	0.670	70
358.33	14.9	31.72	16.02	8.25	0.397	0.755	66
380.42	15.9	29.77	15.03	9.23	0.445	0.845	62
409.50	17.1	28.23	14.26	10.01	0.482	0.917	59
429.92	17.9	27.01	13.64	10.63	0.512	0.973	56
454.08	18.9	25.84	13.05	11.22	0.540	1.027	54
478.08	19.9	24.93	12.59	11.68	0.562	1.069	52

APPENDIX E

STIRRED JAR BATCH TEST NUMBER 7

pH: 7
ISS CONC. OF ALUM SLUDGE: 1384 mg/l
INITIAL VOLUME: 490 ml
VOLUME ALUM DOSED: 40 ml

MASS ALUM ISS DOSED: 55.36 mgISS
EQUIV. Al MASS DOSED 29.12 mgAl
P initial/ISS added: 0.203

TIME hours	TIME days	P CONC. mgP/l	P MASS mgP	MASS P REMOVED mgP	mgP rem/ mgISS add mgP/mgISS	mgP rem/ mgAl add mgP/mgAl	% P remaining
0.00	0.0	21.21	11.24	0	0.000	0.000	100
0.08	0.0	16.91	8.96	2.28	0.041	0.078	80
22.17	0.9	11.28	5.98	5.26	0.095	0.181	53
44.42	1.9	8.42	4.46	6.78	0.122	0.233	40
73.17	3.0	9.02	4.78	6.46	0.117	0.222	43
94.00	3.9	5.82	3.08	8.16	0.147	0.280	27
118.00	4.9	4.90	2.60	8.64	0.156	0.297	23
141.92	5.9	4.57	2.42	8.82	0.159	0.303	22
166.72	6.9	3.35	1.78	9.47	0.171	0.325	16
189.92	7.9	3.05	1.62	9.62	0.174	0.331	14
213.33	8.9	2.07	1.10	10.14	0.183	0.348	10
240.17	10.0	1.77	0.94	10.30	0.186	0.354	8
262.17	10.9	1.77	0.94	10.30	0.186	0.354	8
286.00	11.9	2.78	1.47	9.77	0.176	0.335	13
309.83	12.9	1.26	0.67	10.57	0.191	0.363	6
333.92	13.9	1.54	0.82	10.43	0.188	0.358	7
358.33	14.9	1.23	0.65	10.59	0.191	0.364	6
380.42	15.9	0.61	0.32	10.92	0.197	0.375	3
409.50	17.1	0.31	0.16	11.08	0.200	0.380	1
429.92	17.9	0.61	0.32	10.92	0.197	0.375	3
454.08	18.9	1.22	0.65	10.59	0.191	0.364	6
478.08	19.9	0.66	0.35	10.89	0.197	0.374	3

APPENDIX E

STIRRED JAR BATCH TEST NUMBER 8

pH: 7
ISS CONC. OF ALUM SLUDGE: 1384 mg/l
INITIAL VOLUME: 490 ml
VOLUME ALUM DOSED: 25 ml

MASS ALUM ISS DOSED: 34.6 mgISS
EQUIV. Al MASS DOSED 18.20 mgAl
P initial/ISS added: 0.334

TIME hours	TIME days	P CONC. mgP/l	P MASS mgP	MASS P REMOVED mgP	mgP rem/ mgISS add mgP/mgISS	mgP rem/ mgAl add mgP/mgAl	% P remaining
0.00	0.0	22.41	11.54	0	0.000	0.000	100
0.08	0.0	20.54	10.58	0.96	0.028	0.053	92
22.17	0.9	15.85	8.16	3.38	0.098	0.186	71
44.42	1.9	14.74	7.59	3.95	0.114	0.217	66
73.17	3.0	11.73	6.04	5.50	0.159	0.302	52
94.00	3.9	10.71	5.52	6.03	0.174	0.331	48
118.00	4.9	9.79	5.04	6.50	0.188	0.357	44
141.92	5.9	8.52	4.39	7.15	0.207	0.393	38
166.72	6.9	7.91	4.07	7.47	0.216	0.410	35
189.92	7.9	6.70	3.45	8.09	0.234	0.445	30
213.33	8.9	5.32	2.74	8.80	0.254	0.484	24
240.17	10.0	4.44	2.29	9.25	0.267	0.509	20
262.17	10.9	3.84	1.98	9.56	0.276	0.525	17
286.00	11.9	3.39	1.75	9.80	0.283	0.538	15
309.83	12.9	3.15	1.62	9.92	0.287	0.545	14
333.92	13.9	2.16	1.11	10.43	0.301	0.573	10
358.33	14.9	1.54	0.79	10.75	0.311	0.591	7
380.42	15.9	0.92	0.47	11.07	0.320	0.608	4
409.50	17.1	0.61	0.31	11.23	0.324	0.617	3
429.92	17.9	0.92	0.47	11.07	0.320	0.608	4
454.08	18.9	1.22	0.63	10.91	0.315	0.600	5
478.08	19.9	0.66	0.34	11.20	0.324	0.615	3

APPENDIX E

STIRRED JAR BATCH TEST NUMBER 9

pH: 7
ISS CONC. OF ALUM SLUDGE: 1384 mg/l
INITIAL VOLUME: 490 ml
VOLUME ALUM DOSED: 15 ml

MASS ALUM ISS DOSED: 20.76 mgISS
EQUIV. Al MASS DOSED 10.92 mgAl
P initial/ISS added: 0.556

TIME hours	TIME days	P CONC. mgP/l	P MASS mgP	MASS P REMOVED mgP	mgP rem/ mgISS add mgP/mgISS	mgP rem/ mgAl add mgP/mgAl	% P remaining
0.00	0.0	22.86	11.54	0	0.000	0.000	100
0.08	0.0	20.84	10.52	1.02	0.049	0.093	91
22.17	0.9	17.99	9.08	2.46	0.118	0.225	79
44.42	1.9	16.24	8.20	3.34	0.161	0.306	71
73.17	3.0	14.74	7.44	4.10	0.198	0.376	64
94.00	3.9	14.38	7.26	4.28	0.206	0.392	63
118.00	4.9	13.47	6.80	4.74	0.228	0.434	59
141.92	5.9	11.87	5.99	5.55	0.267	0.508	52
166.72	6.9	10.95	5.53	6.01	0.290	0.551	48
189.92	7.9	9.75	4.92	6.62	0.319	0.606	43
213.33	8.9	8.57	4.33	7.22	0.348	0.661	37
240.17	10.0	8.28	4.18	7.36	0.355	0.674	36
262.17	10.9	7.39	3.73	7.81	0.376	0.715	32
286.00	11.9	5.86	2.96	8.59	0.414	0.786	26
309.83	12.9	5.68	2.87	8.68	0.418	0.795	25
333.92	13.9	4.93	2.49	9.05	0.436	0.829	22
358.33	14.9	3.69	1.86	9.68	0.466	0.887	16
380.42	15.9	3.07	1.55	9.99	0.481	0.915	13
409.50	17.1	2.46	1.24	10.30	0.496	0.943	11
429.92	17.9	3.99	2.01	9.53	0.459	0.873	17
454.08	18.9	3.04	1.54	10.01	0.482	0.917	13
478.08	19.9	2.37	1.20	10.35	0.498	0.948	10

APPENDIX E

STIRRED JAR BATCH TEST NUMBER 10

pH: 7.3
ISS CONC. OF ALUM SLUDGE: 1384 mg/l
INITIAL VOLUME: 490 ml
VOLUME ALUM DOSED: 40 ml

MASS ALUM ISS DOSED: 55.36 mgISS
EQUIV. Al MASS DOSED 29.12 mgAl
P initial/ISS added: 0.450

TIME hours	TIME days	P CONC. mgP/l	P MASS mgP	MASS P REMOVED mgP	mgP rem/ mgISS add mgP/mgISS	mgP rem/ mgAl add mgP/mgAl	% P remaining
0.00	0.0	47.04	24.93	0	0.000	0.000	100
0.17	0.0	42.16	22.34	2.59	0.047	0.089	90
9.83	0.4	38.28	20.29	4.64	0.084	0.159	81
22.92	1.0	36.46	19.32	5.61	0.101	0.193	78
32.33	1.3	35.11	18.61	6.32	0.114	0.217	75
46.50	1.9	35.42	18.77	6.16	0.111	0.211	75
70.08	2.9	33.95	17.99	6.94	0.125	0.238	72
93.28	3.9	32.71	17.34	7.59	0.137	0.261	70
119.92	5.0	32.28	17.11	7.82	0.141	0.269	69
143.58	6.0	31.17	16.52	8.41	0.152	0.289	66
165.75	6.9	29.96	15.88	9.05	0.164	0.311	64
190.33	7.9	30.35	16.09	8.85	0.160	0.304	65
213.75	8.9	28.51	15.11	9.82	0.177	0.337	61
238.08	9.9	25.72	13.63	11.30	0.204	0.388	55
261.92	10.9	25.10	13.30	11.63	0.210	0.399	53
288.17	12.0	22.73	12.05	12.88	0.233	0.442	48
309.42	12.9	22.11	11.72	13.21	0.239	0.454	47
333.75	13.9	21.49	11.39	13.54	0.245	0.465	46
357.42	14.9	17.86	9.47	15.47	0.279	0.531	38
383.00	16.0	14.73	7.81	17.12	0.309	0.588	31
406.92	17.0	12.73	6.75	18.18	0.328	0.624	27
429.75	17.9	10.91	5.78	19.15	0.346	0.658	23
502.08	20.9	7.18	3.81	21.13	0.382	0.725	15
550.17	22.9	6.93	3.67	21.26	0.384	0.730	15
597.75	24.9	5.27	2.79	22.14	0.400	0.760	11

APPENDIX E

STIRRED JAR BATCH TEST NUMBER 11

pH: 7.3
ISS CONC. OF ALUM SLUDGE: 1384 mg/l
INITIAL VOLUME: 490 ml
VOLUME ALUM DOSED: 20 ml

MASS ALUM ISS DOSED: 27.68 mgISS
EQUIV. Al MASS DOSED 14.56 mgAl
P initial/ISS added: 0.912

TIME hours	TIME days	P CONC. mgP/l	P MASS mgP	MASS P REMOVED mgP	mgP rem/ mgISS add mgP/mgISS	mgP rem/ mgAl add mgP/mgAl	% P remaining
0.00	0.0	49.49	25.24	0	0.000	0.000	100
0.08	0.0	46.17	23.55	1.69	0.061	0.116	93
10.08	0.4	44.36	22.62	2.62	0.095	0.180	90
23.17	1.0	44.36	22.62	2.62	0.095	0.180	90
32.67	1.4	44.35	22.62	2.62	0.095	0.180	90
46.83	2.0	43.43	22.15	3.09	0.112	0.212	88
70.33	2.9	42.98	21.92	3.32	0.120	0.228	87
94.25	3.9	42.80	21.83	3.41	0.123	0.234	86
120.25	5.0	40.86	20.84	4.40	0.159	0.302	83
143.83	6.0	39.95	20.37	4.87	0.176	0.334	81
166.00	6.9	39.95	20.37	4.87	0.176	0.334	81
190.67	7.9	38.62	19.70	5.54	0.200	0.381	78
214.00	8.9	38.62	19.70	5.54	0.200	0.381	78
238.33	9.9	36.87	18.80	6.44	0.233	0.442	74
262.25	10.9	35.94	18.33	6.91	0.250	0.475	73
288.42	12.0	34.87	17.78	7.46	0.269	0.512	70
309.75	12.9	34.56	17.63	7.61	0.275	0.523	70
334.08	13.9	33.32	16.99	8.25	0.298	0.566	67
358.25	14.9	31.02	15.82	9.42	0.340	0.647	63
383.25	16.0	28.52	14.55	10.69	0.386	0.735	58
407.17	17.0	26.97	13.75	11.49	0.415	0.789	54
430.17	17.9	24.24	12.36	12.88	0.465	0.884	49
502.33	20.9	18.73	9.55	15.69	0.567	1.077	38
550.42	22.9	18.26	9.31	15.93	0.575	1.094	37
598.08	24.9	14.58	7.44	17.80	0.643	1.223	29

APPENDIX E

STIRRED JAR BATCH TEST NUMBER 12

pH: 7.3
ISS CONC. OF ALUM SLUDGE: 1384 mg/l
INITIAL VOLUME: 490 ml
VOLUME ALUM DOSED: 10 ml

MASS ALUM ISS DOSED: 13.84 mgISS
EQUIV. Al MASS DOSED 7.28 mgAl
P initial/ISS added: 1.845

TIME hours	TIME days	P CONC. mgP/l	P MASS mgP	MASS P REMOVED mgP	mgP rem/ mgISS add mgP/mgISS	mgP rem/ mgAl add mgP/mgAl	% P remaining
0.00	0.0	51.07	25.54	0	0.000	0.000	100
0.17	0.0	48.01	24.01	1.53	0.111	0.210	94
8.83	0.4	48.61	24.31	1.23	0.089	0.169	95
22.83	1.0	47.70	23.85	1.68	0.122	0.231	93
32.25	1.3	46.51	23.26	2.28	0.165	0.313	91
46.42	1.9	45.89	22.95	2.59	0.187	0.356	90
70.00	2.9	46.40	23.20	2.34	0.169	0.321	91
93.83	3.9	46.16	23.08	2.46	0.177	0.337	90
119.83	5.0	45.70	22.85	2.68	0.194	0.369	89
143.50	6.0	44.79	22.40	3.14	0.227	0.431	88
165.75	6.9	44.49	22.25	3.29	0.238	0.452	87
190.33	7.9	44.45	22.23	3.31	0.239	0.455	87
213.75	8.9	42.91	21.46	4.08	0.295	0.560	84
238.08	9.9	42.76	21.38	4.16	0.300	0.571	84
261.92	10.9	43.38	21.69	3.84	0.278	0.528	85
288.08	12.0	41.41	20.71	4.83	0.349	0.663	81
309.33	12.9	41.73	20.87	4.67	0.337	0.641	82
333.67	13.9	41.73	20.87	4.67	0.337	0.641	82
358.00	14.9	40.11	20.06	5.48	0.396	0.753	79
383.08	16.0	39.17	19.59	5.95	0.430	0.817	77
407.08	17.0	38.18	19.09	6.45	0.466	0.885	75
429.83	17.9	37.27	18.64	6.90	0.499	0.948	73
502.17	20.9	37.15	18.58	6.96	0.503	0.956	73
550.08	22.9	36.83	18.42	7.12	0.514	0.978	72
597.66	24.9	36.29	18.15	7.39	0.534	1.015	71

APPENDIX E

STIRRED JAR BATCH TEST NUMBER 13

pH: 7.5
ISS CONC. OF ALUM SLUDGE: 1384 mg/l
INITIAL VOLUME: 490 ml
VOLUME ALUM DOSED: 40 ml

MASS ALUM ISS DOSED: 55.36 mgISS
EQUIV. Al MASS DOSED 29.12 mgAl
P initial/ISS added: 0.436

TIME hours	TIME days	P CONC. mgP/l	P MASS mgP	MASS P REMOVED mgP	mgP rem/ mgISS add mgP/mgISS	mgP rem/ mgAl add mgP/mgAl	% P remaining
0.00	0.0	45.51	24.12	0	0.000	0.000	100
0.08	0.0	39.87	21.13	2.99	0.054	0.103	88
22.08	0.9	35.67	18.91	5.22	0.094	0.179	78
44.42	1.9	33.39	17.70	6.42	0.116	0.221	73
73.17	3.0	32.79	17.38	6.74	0.122	0.232	72
94.00	3.9	30.30	16.06	8.06	0.146	0.277	67
118.00	4.9	29.38	15.57	8.55	0.154	0.294	65
141.92	5.9	29.52	15.65	8.47	0.153	0.291	65
166.72	6.9	27.68	14.67	9.45	0.171	0.325	61
189.92	7.9	26.49	14.04	10.08	0.182	0.346	58
213.33	8.9	24.84	13.17	10.96	0.198	0.376	55
240.17	10.0	23.65	12.53	11.59	0.209	0.398	52
262.17	10.9	22.47	11.91	12.21	0.221	0.419	49
286.00	11.9	23.14	12.26	11.86	0.214	0.407	51
309.83	12.9	20.82	11.03	13.09	0.236	0.449	46
333.92	13.9	19.09	10.12	14.00	0.253	0.481	42
358.33	14.9	16.94	8.98	15.14	0.274	0.520	37
380.42	15.9	15.34	8.13	15.99	0.289	0.549	34
409.50	17.1	13.81	7.32	16.80	0.303	0.577	30
429.92	17.9	12.58	6.67	17.45	0.315	0.599	28
454.08	18.9	12.61	6.68	17.44	0.315	0.599	28
478.08	19.9	12.31	6.52	17.60	0.318	0.604	27

APPENDIX E

STIRRED JAR BATCH TEST NUMBER 14

pH: 7.5
ISS CONC. OF ALUM SLUDGE: 1384 mg/l
INITIAL VOLUME: 490 ml
VOLUME ALUM DOSED: 25 ml

MASS ALUM ISS DOSED: 34.6 mgISS
EQUIV. Al MASS DOSED 18.20 mgAl
P initial/ISS added: 0.667

TIME hours	TIME days	P CONC. mgP/l	P MASS mgP	MASS P REMOVED mgP	mgP rem/ mgISS add mgP/mgISS	mgP rem/ mgAl add mgP/mgAl	% P remaining
0.00	0.0	44.81	23.08	0	0.000	0.000	100
0.08	0.0	42.28	21.77	1.30	0.038	0.072	94
22.08	0.9	38.41	19.78	3.30	0.095	0.181	86
44.42	1.9	35.80	18.44	4.64	0.134	0.255	80
73.17	3.0	33.39	17.20	5.88	0.170	0.323	75
94.00	3.9	33.67	17.34	5.74	0.166	0.315	75
118.00	4.9	31.52	16.23	6.84	0.198	0.376	70
141.92	5.9	30.44	15.68	7.40	0.214	0.407	68
166.72	6.9	30.11	15.51	7.57	0.219	0.416	67
189.92	7.9	28.93	14.90	8.18	0.236	0.449	65
213.33	8.9	28.39	14.62	8.46	0.244	0.465	63
240.17	10.0	26.02	13.40	9.68	0.280	0.532	58
262.17	10.9	26.02	13.40	9.68	0.280	0.532	58
286.00	11.9	24.07	12.40	10.68	0.309	0.587	54
309.83	12.9	23.03	11.86	11.22	0.324	0.616	51
333.92	13.9	21.56	11.10	11.97	0.346	0.658	48
358.33	14.9	19.09	9.83	13.25	0.383	0.728	43
380.42	15.9	19.03	9.80	13.28	0.384	0.730	42
409.50	17.1	16.57	8.53	14.54	0.420	0.799	37
429.92	17.9	15.04	7.75	15.33	0.443	0.842	34
454.08	18.9	16.42	8.46	14.62	0.423	0.803	37
478.08	19.9	15.34	7.90	15.18	0.439	0.834	34

APPENDIX E

STIRRED JAR BATCH TEST NUMBER 15

pH: 7.8
ISS CONC. OF ALUM SLUDGE: 1384 mg/l
INITIAL VOLUME: 490 ml
VOLUME ALUM DOSED: 40 ml

MASS ALUM ISS DOSED: 55.36 mgISS
EQUIV. Al MASS DOSED 29.12 mgAl
P initial/ISS added: 0.475

TIME hours	TIME days	P CONC. mgP/l	P MASS mgP	MASS P REMOVED mgP	mgP rem/ mgISS add mgP/mgISS	mgP rem/ mgAl add mgP/mgAl	% P remaining
0.00	0.0	49.61	26.29	0	0.000	0.000	100
0.17	0.0	44.01	23.33	2.97	0.054	0.102	89
9.08	0.4	41.01	21.74	4.56	0.082	0.157	83
22.67	0.9	39.49	20.93	5.36	0.097	0.184	80
32.25	1.3	37.58	19.92	6.38	0.115	0.219	76
46.17	1.9	36.35	19.27	7.03	0.127	0.241	73
69.75	2.9	35.81	18.98	7.31	0.132	0.251	72
93.58	3.9	37.29	19.76	6.53	0.118	0.224	75
119.25	5.0	36.92	19.57	6.73	0.121	0.231	74
142.92	6.0	36.32	19.25	7.04	0.127	0.242	73
165.50	6.9	36.02	19.09	7.20	0.130	0.247	73
190.00	7.9	36.17	19.17	7.12	0.129	0.245	73
213.33	8.9	35.86	19.01	7.29	0.132	0.250	72
237.58	9.9	34.39	18.23	8.07	0.146	0.277	69
261.67	10.9	34.39	18.23	8.07	0.146	0.277	69
287.75	12.0	31.45	16.67	9.62	0.174	0.331	63
309.25	12.9	32.38	17.16	9.13	0.165	0.314	65
333.42	13.9	32.38	17.16	9.13	0.165	0.314	65
356.58	14.9	28.83	15.28	11.01	0.199	0.378	58
382.92	16.0	29.14	15.44	10.85	0.196	0.373	59
406.83	17.0	28.18	14.94	11.36	0.205	0.390	57
429.58	17.9	27.57	14.61	11.68	0.211	0.401	56
501.92	20.9	26.85	14.23	12.06	0.218	0.414	54
549.83	22.9	26.44	14.01	12.28	0.222	0.422	53
597.58	24.9	23.89	12.66	13.63	0.246	0.468	48

APPENDIX E

STIRRED JAR BATCH TEST NUMBER 16

pH: 7.8
ISS CONC. OF ALUM SLUDGE: 1384 mg/l
INITIAL VOLUME: 490 ml
VOLUME ALUM DOSED: 20 ml

MASS ALUM ISS DOSED: 27.68 mgISS
EQUIV. Al MASS DOSED 14.56 mgAl
P initial/ISS added: 0.928

TIME hours	TIME days	P CONC. mgP/l	P MASS mgP	MASS P REMOVED mgP	mgP rem/ mgISS add mgP/mgISS	mgP rem/ mgAl add mgP/mgAl	% P remaining
0.00	0.0	50.37	25.69	0	0.000	0.000	100
0.08	0.0	46.47	23.70	1.99	0.072	0.137	92
9.67	0.4	44.96	22.93	2.76	0.100	0.190	89
22.83	1.0	45.57	23.24	2.45	0.088	0.168	90
32.58	1.4	44.35	22.62	3.07	0.111	0.211	88
46.42	1.9	43.12	21.99	3.70	0.134	0.254	86
69.92	2.9	43.91	22.39	3.29	0.119	0.226	87
93.92	3.9	43.41	22.14	3.55	0.128	0.244	86
119.92	5.0	42.07	21.46	4.23	0.153	0.291	84
143.50	6.0	42.37	21.61	4.08	0.147	0.280	84
165.75	6.9	41.46	21.14	4.54	0.164	0.312	82
190.17	7.9	43.22	22.04	3.65	0.132	0.250	86
213.67	8.9	40.46	20.63	5.05	0.183	0.347	80
237.92	9.9	40.59	20.70	4.99	0.180	0.343	81
262.00	10.9	36.87	18.80	6.88	0.249	0.473	73
288.00	12.0	35.50	18.11	7.58	0.274	0.521	70
309.33	12.9	35.81	18.26	7.43	0.268	0.510	71
333.67	13.9	33.94	17.31	8.38	0.303	0.576	67
357.92	14.9	33.53	17.10	8.59	0.310	0.590	67
383.00	16.0	33.22	16.94	8.75	0.316	0.601	66
406.92	17.0	32.72	16.69	9.00	0.325	0.618	65
429.75	17.9	31.81	16.22	9.47	0.342	0.650	63
502.08	20.9	31.22	15.92	9.77	0.353	0.671	62
550.00	22.9	28.96	14.77	10.92	0.394	0.750	57
597.58	24.9	29.47	15.03	10.66	0.385	0.732	59

APPENDIX E

STIRRED JAR BATCH TEST NUMBER 17

pH: 7.8
ISS CONC. OF ALUM SLUDGE: 1384 mg/l
INITIAL VOLUME: 490 ml
VOLUME ALUM DOSED: 10 ml

MASS ALUM ISS DOSED: 13.84 mgISS
EQUIV. Al MASS DOSED 7.28 mgAl
P initial/ISS added: 1.845

TIME hours	TIME days	P CONC. mgP/l	P MASS mgP	MASS P REMOVED mgP	mgP rem/ mgISS add mgP/mgISS	mgP rem/ mgAl add mgP/mgAl	% P remaining
0.00	0.0	51.07	25.54	0	0.000	0.000	100
0.25	0.0	48.32	24.16	1.38	0.099	0.189	95
8.58	0.4	47.09	23.55	1.99	0.144	0.273	92
22.83	1.0	47.09	23.55	1.99	0.144	0.273	92
32.50	1.4	46.20	23.10	2.43	0.176	0.334	90
46.33	1.9	45.59	22.80	2.74	0.198	0.376	89
69.92	2.9	46.09	23.05	2.49	0.180	0.342	90
93.83	3.9	44.94	22.47	3.07	0.221	0.421	88
119.83	5.0	46.31	23.16	2.38	0.172	0.327	91
143.42	6.0	44.79	22.40	3.14	0.227	0.431	88
165.67	6.9	44.49	22.25	3.29	0.238	0.452	87
190.17	7.9	44.75	22.38	3.16	0.228	0.434	88
213.58	8.9	44.14	22.07	3.47	0.250	0.476	86
237.83	9.9	44.62	22.31	3.23	0.233	0.443	87
261.92	10.9	43.69	21.85	3.69	0.267	0.507	86
288.00	12.0	42.04	21.02	4.52	0.326	0.620	82
309.33	12.9	42.66	21.33	4.21	0.304	0.578	84
333.67	13.9	41.41	20.71	4.83	0.349	0.663	81
358.00	14.9	40.11	20.06	5.48	0.396	0.753	79
383.08	16.0	39.17	19.59	5.95	0.430	0.817	77
407.00	17.0	36.96	18.48	7.06	0.510	0.969	72
429.83	17.9	35.75	17.88	7.66	0.553	1.052	70
502.08	20.9	36.53	18.27	7.27	0.525	0.999	72
550.00	22.9	36.83	18.42	7.12	0.514	0.978	72
597.75	24.9	36.29	18.15	7.39	0.534	1.015	71

APPENDIX E

STIRRED JAR BATCH TEST NUMBER 18

pH: 7
COMMERCIAL ALUM CONC 8806.5 mgAl2(SO4)3.18H2O/l
INITIAL VOLUME: 490 ml
VOLUME ALUM DOSED: 40 ml

MASS ALUM DOSED : 352.26 mgISS
EQUIV. Al MASS DOSED 28.55 mgAl
P initial/Al added: 0.819
P initial/ISS added: 0.434

TIME hours	TIME days	P CONC. mgP/l	P MASS mgP	MASS P REMOVED mgP	mgP rem/ mgISS add mgP/mgISS	mgP rem/ mgAl add mgP/mgAl	% P remaining
0.00	0.0	44.11	23.38	0	0.000	0.000	100
0.33	0.0	8.72	4.62	18.76	0.053	0.657	20
28.67	1.2	34.59	18.33	5.05	0.014	0.177	78
49.83	2.1	3.37	1.79	21.59	0.061	0.756	8
73.42	3.1	19.28	10.22	13.16	0.037	0.461	44
97.83	4.1	21.91	11.61	11.77	0.033	0.412	50
122.33	5.1	19.47	10.32	13.06	0.037	0.457	44
145.75	6.1	20.40	10.81	12.57	0.036	0.440	46
217.67	9.1	10.64	5.64	17.74	0.050	0.621	24
241.58	10.1	8.64	4.58	18.80	0.053	0.659	20
265.58	11.1	7.57	4.01	19.37	0.055	0.678	17
289.67	12.1	2.46	1.30	22.07	0.063	0.773	6
314.17	13.1	1.54	0.82	22.56	0.064	0.790	3
385.92	16.1	0.92	0.49	22.89	0.065	0.802	2
410.08	17.1	1.82	0.96	22.41	0.064	0.785	4
434.08	18.1	1.23	0.65	22.73	0.065	0.796	3

APPENDIX E

STIRRED JAR BATCH TEST NUMBER 19

pH: 7
COMMERCIAL ALUM CONC 8806.5 mgAl2(SO4)3.18H2O/l
INITIAL VOLUME: 490 ml
VOLUME ALUM DOSED: 25 ml

MASS ALUM DOSED :220.1625 mgISS
EQUIV. Al MASS DOSED 17.84 mgAl
P initial/Al added: 1.319
P initial/ISS added: 0.699

TIME hours	TIME days	P CONC. mgP/l	P MASS mgP	MASS P REMOVED mgP	mgP rem/ mgISS add mgP/mgISS	mgP rem/ mgAl add mgP/mgAl	% P remaining
0.00	0.0	45.68	23.53	0	0.000	0.000	100
0.17	0.0	19.85	10.22	13.30	0.060	0.746	43
28.58	1.2	24.67	12.71	10.82	0.049	0.606	54
49.58	2.1	26.32	13.55	9.97	0.045	0.559	58
73.25	3.1	23.26	11.98	11.55	0.052	0.647	51
97.58	4.1	25.26	13.01	10.52	0.048	0.589	55
122.17	5.1	23.42	12.06	11.46	0.052	0.643	51
145.50	6.1	21.06	10.85	12.68	0.058	0.711	46
217.42	9.1	11.83	6.09	17.43	0.079	0.977	26
241.33	10.1	9.26	4.77	18.76	0.085	1.051	20
265.42	11.1	7.89	4.06	19.46	0.088	1.091	17
289.42	12.1	3.70	1.91	21.62	0.098	1.212	8
313.92	13.1	3.08	1.59	21.94	0.100	1.230	7
385.75	16.1	1.23	0.63	22.89	0.104	1.283	3
409.92	17.1	1.22	0.63	22.90	0.104	1.283	3
433.92	18.1	1.54	0.79	22.73	0.103	1.274	3

APPENDIX E

STIRRED JAR BATCH TEST NUMBER 20

pH: 7
COMMERCIAL ALUM CONC 8806.5 mgAl2(SO4)3.18H2O/l
INITIAL VOLUME: 490 ml
VOLUME ALUM DOSED: 15 ml

MASS ALUM DOSED :132.0975 mgISS
EQUIV. Al MASS DOSED 10.70 mgAl
P initial/Al added: 2.184
P initial/ISS added: 1.158

TIME hours	TIME days	P CONC. mgP/l	P MASS mgP	MASS P REMOVED mgP	mgP rem/ mgISS add mgP/mgISS	mgP rem/ mgAl add mgP/mgAl	% P remaining
0.00	0.0	46.30	23.38	0	0.000	0.000	100
0.08	0.0	32.19	16.26	7.13	0.054	0.666	70
28.58	1.2	30.08	15.19	8.19	0.062	0.765	65
49.58	2.1	28.16	14.22	9.16	0.069	0.856	61
73.25	3.1	37.64	19.01	4.37	0.033	0.409	81
97.58	4.1	34.70	17.52	5.86	0.044	0.547	75
122.17	5.1	33.16	16.75	6.64	0.050	0.620	72
145.50	6.1	30.15	15.23	8.16	0.062	0.762	65
217.42	9.1	19.81	10.00	13.38	0.101	1.250	43
241.33	10.1	18.82	9.50	13.88	0.105	1.296	41
265.42	11.1	15.14	7.65	15.74	0.119	1.470	33
289.42	12.1	13.86	7.00	16.38	0.124	1.530	30
313.92	13.1	11.39	5.75	17.63	0.133	1.647	25
385.75	16.1	7.06	3.57	19.82	0.150	1.851	15
409.92	17.1	6.08	3.07	20.31	0.154	1.897	13
433.92	18.1	5.32	2.69	20.69	0.157	1.933	11

APPENDIX E

REGRESSION ANALYSIS OF 20 DAY DATA FROM BATCH TESTS

INDEPENDANT VARIABLES: LOG (INITIAL P MASS/ISS MASS DOSED)
DEPENDANT VARIABLES: P REMOVAL EXPRESSED AS A PERCENTAGE OF STOICHIOMETRIC REMOVAL

pH 6.8

BATCH TEST NUMBER	mgP init/ mgISS dosed mgP/mgISS	LOG(Pinit/ ISS dosed)	STOICH REMOVAL %
1	0.467	-0.761	70
2	0.917	-0.087	112
3	1.834	0.606	127

Regression Output:

Constant	106.3481
Std Err of Y Est	11.33484
R Squared	0.926415
No. of Observations	3
Degrees of Freedom	1
X Coefficient(s)	41.57809
Std Err of Coef.	11.71904

pH 7.0

BATCH TEST NUMBER	mgP init/ mgISS dosed mgP/mgISS	LOG(Pinit/ ISS dosed)	STOICH REMOVAL %
7	0.203	-0.692	32
8	0.334	-0.476	53
9	0.556	-0.255	82
6	1.169	0.068	92

Regression Output:

Constant	92.31348
Std Err of Y Est	8.911123
R Squared	0.929439
No. of Observations	4
Degrees of Freedom	2
X Coefficient(s)	81.31603
Std Err of Coef.	15.8429

pH 6.8-7.0

BATCH TEST NUMBER	mgP init/ mgISS dosed mgP/mgISS	LOG(Pinit/ ISS dosed)	STOICH REMOVAL %
7	0.203	-0.693	32
8	0.334	-0.476	53
1	0.467	-0.331	70
9	0.556	-0.255	82
2	0.917	-0.038	112
6	1.169	0.068	92
3	1.834	0.263	127

Regression Output:

Constant	101.187
Std Err of Y Est	9.964289
R Squared	0.923682
No. of Observations	7
Degrees of Freedom	5
X Coefficient(s)	96.05047
Std Err of Coef.	12.34712

APPENDIX E

REGRESSION ANALYSIS OF 20 DAY DATA FROM BATCH TESTS

INDEPENDANT VARIABLES: LOG (INITIAL P MASS/ISS MASS DOSED)
DEPENDANT VARIABLES: P REMOVAL EXPRESSED AS A PERCENTAGE OF STOICHIOMETRIC REMOVAL

pH 7.3-7.5

BATCH TEST NUMBER	mgP init/ mgISS dosed mgP/mgISS	LOG(Pinit/ ISS dosed)	STOICH REMOVAL %
13	0.436	-0.361	52
10	0.450	-0.347	63
14	0.667	-0.176	72
11	0.912	-0.040	93

Regression Output:

Constant	95.31489
Std Err of Y Est	5.80801
R Squared	0.925534
No. of Observations	4
Degrees of Freedom	2
X Coefficient(s)	109.6856
Std Err of Coef.	21.99969

pH 7.8

BATCH TEST NUMBER	mgP init/ mgISS dosed mgP/mgISS	LOG(Pinit/ ISS dosed)	STOICH REMOVAL %
15	0.475	-0.323	36
16	0.928	-0.032	58
17	1.845	0.266	86

Regression Output:

Constant	62.53982
Std Err of Y Est	2.195385
R Squared	0.995194
No. of Observations	3
Degrees of Freedom	1
X Coefficient(s)	84.98507
Std Err of Coef.	5.24678

REGRESSION ANALYSIS USING COMMERCIAL ALUMINIUM SULPHATE AS A PRECIPITANT

pH 7.0

BATCH TEST NUMBER	mgP init/ mgISS dosed mgP/mgISS	LOG(Pinit/ ISS dosed)	STOICH REMOVAL %
18	0.433	-0.3635121	69
19	0.698	-0.1561446	111
20	1.156	0.06295783	168

Regression Output:

Constant	151.3793
Std Err of Y Est	5.010976
R Squared	0.994915
No. of Observations	3
Degrees of Freedom	1
X Coefficient(s)	232.4022
Std Err of Coef.	16.61476

APPENDIX 5

REGRESSION ANALYSIS OF 20 DAY DATA FROM BATCH TESTS

INDEPENDANT VARIABLES: LOG (INITIAL P MASS/ISS MASS DOSED)
DEPENDANT VARIABLES: P REMOVAL EXPRESSED AS A PERCENTAGE OF STOICHIOMETRIC REMOVAL

REGRESSION ANALYSIS ON DATA IN THE pH RANGE 6.8-7.0 USING ALUM SLUDGE
WITH ISS MASSES CONVERTED TO EQUIVALENT ALUMINIUM MASSES

BATCH TEST NUMBER	mgP init/ mgAl dosed mgP/mgAl	LOG(Pinit/ Al dosed)	STOICH REMOVAL %
7	0.290	-0.409	32
9	0.642	-0.192	53
1	0.898	-0.047	70
9	1.069	0.029	82
2	1.763	0.246	112
6	2.248	0.352	92
3	3.257	0.513	127

Regression Output:

Constant	74.23292
Std Err of Y Est	10.05964
R Squared	0.922215
No. of Observations	7
Degrees of Freedom	5
X Coefficient(s)	98.35391
Std Err of Coef.	12.77436

REGRESSION ANALYSIS USING COMMERCIAL ALUMINIUM SULPHATE AS A PRECIPITANT

BATCH TEST NUMBER	mgP init/ mgAl dosed mgP/mgAl	LOG(Pinit/ Al dosed)	STOICH REMOVAL %
18	0.819	-0.087	69
19	1.319	0.120	111
20	2.185	0.339	169

Regression Output:

Constant	87.08458
Std Err of Y Est	4.961599
R Squared	0.995015
No. of Observations	3
Degrees of Freedom	1
X Coefficient(s)	232.5761
Std Err of Coef.	16.46282